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Movements used during turning and factors influencing the way in which people with Parkinson's Disease turn

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ABSTRACT

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Doctor of Philosophy

MOVEMENTS USED DURING TURNING AND FACTORS INFLUENCING THE WAY IN WHICH PEOPLE WITH PARKINSON'S DISEASE TURN

By Emma Stack

Dysfunctional Turning (a loss of continuity and/or stability when attempting to turn) is a common experience for people with Parkinson's Disease (PD). Rotational gait has been less comprehensively investigated than straight forward parkinsonian gait. Difficulty turning causes freezing and falls but evidence-based avenues for intervention are poorly developed. In this thesis, a tool with which to describe turning, the *Standing Start 180° Turn Test* (SS-180) was developed and used to describe how people with and without PD turned to walk from a standing start. Seventy descriptors of turning were identified from five sources (including the literature). These were reduced to a shortlist of 20 considered important and measurable from video, from which the SS-180 was designed. Participants turned in each direction during the SS-180 and *Turning Steps, Time, Type* and *Quality* were rated. The video-based SS-180 was validated against a laboratory-based 'gold standard' and test-retest stability, intra- and inter-rater reliability was established.

Thirty-three healthy adults (median age 40 years) took part in the first (laboratory-based) study. Turning took a median 2.5 Steps in a median 1.5s. *Toward* (36%) and *Pivotal* (33%) Turn Types were common; Quality was maximal (five/five) for all but one turn. Seven people with PD (median age 77, median PD duration eight years) took part in a preliminary (laboratory-based) study. Turning took a median six Steps, 3.9s. *Incremental* (71%) Turn Types were common; Quality was sub-maximal in most cases. Twenty-three people with PD (median age 68, median PD duration four years) and ten age-matched controls (median age 70) took part in the main (home-based) study. Participants with PD turned in a median 3.8 Steps, 2s; *Incremental* (64%) Turn Types were common. Controls turned in fewer Steps and faster ($P<0.01$) demonstrating different Turn Types ($P<0.05$). Dysfunctional turning was common among the samples of people with PD recruited. Balance control, age and PD severity were the key correlates of the SS-180. *Directional Asymmetry* was a feature of the way people with PD turned: 28% demonstrated a two Step difference turning each direction (*v* none of the participants without PD). People with PD who took five or more Turning Steps in the freely chosen direction were likely to demonstrate dysfunction when turning in the opposite direction (positive prediction value was 79% in this study).

Turning is highly balance-demanding and the features of parkinsonian turning may reflect adaptation of the basic turn to enhance stability. Further studies are required to establish whether dysfunctional turning, the characteristic parkinsonian turn and/or directional asymmetry have any diagnostic or prognostic value in the management of PD. Suggested therapeutic interventions include balance retraining and increasing axial rotation as well as promoting adaptive (and cognitive) strategies for turning; these would all require further investigation.

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Abbreviations and Definitions

ADL	Activities of Daily Living
ART	Available Response Time
BMD	Bone Mineral Density
CNS	Central Nervous System
CODA	Computerised Optoelectronic Dynamic Anthropometry
COM	Centre of Mass
CT	CODA Time: Turn Time rated from CODA
DS Turn	Direction-specified Turn (the second turn of the SS-180)
DU Turn	Direction-unspecified Turn (the first turn of the SS-180)
EMG	Electromyography
FET	Fisher's Exact Test
FP	Foot Placement
FR%Height	Height-adjusted Functional Reach
GPe	Globus Pallidus External Nucleus
GPi	Globus Pallidus Internal Nucleus
H & Y	Hoehn and Yahr Grade
Hz	Hertz
IQR	Inter-quartile Range
m/mim	Metres per Minute
PD	Parkinson's Disease
POME	Performance-orientated Mobility Evaluation
SAS	The Self-assessed Parkinson's Disease Disability Scale
SEM	Standard Error of the Mean
SMA	Supplementary Motor Area
SNpC	Substantia Nigra Pars Compacta
SNpR	Substantia Nigra Pars Reticulata
SPECT	Single Photon Emission Computed Tomography
STN	Subthalamic Nucleus
SS-180	The Standing Start 180° Turn Test
TRM	Trunk Roll Motion
UPDRS	The Unified Parkinson's Disease Rating Scale
VT	Video Time: Turn Time as rated from Video.

Descriptors of Turning Any terminology that has been used to describe a turn or a component of turning or the ability to turn.

Dysfunctional Turning Loss of continuity and/or stability when attempting to turn.

Fall-events Actual falls and near-misses.

Healthy Adult Study The laboratory-based study described in Chapter 5.

Inside Foot The foot ipsilateral to the direction of turning.

Movement-initiating Foot The first foot observed to move during the SS-180.

Outside Foot The foot contralateral to the direction of turning.

Starting Position Position from which the subject walks during the SS-180; facing away from target at a distance of approximately 3m.

Straight Forward Gait That part of human locomotion that is linear (not rotational) and that advances the individual in the direction in which they are facing.

Turning Steps In SS-180, foot movements that rotate the turner through 180° to face the target.

Turn Time Time from initiation to completion of Turning Steps.

Walking Turns Also known as 'Online Steering': turning while walking continuously.

Chapter One

Introduction to Thesis

The issue central to this thesis is dysfunctional turning when standing and walking, frequently experienced by people with Parkinson's Disease (PD). As turning is a common cause of 'freezing' and falling in PD, in this thesis dysfunctional turning is defined as:

'A loss of continuity and / or stability when attempting to turn'

PD generates numerous motor and non-motor signs and symptoms and people with the condition commonly experience gait impairment. Although the characteristic straight forward parkinsonian gait has been well documented, the *rotational* component of gait has been less well described. This discrepancy is unfortunate because, arguably, turning causes more freezing, falls and injury in PD than does straight forward gait. The term 'straight forward' is not being used to imply simplicity, as it is in everyday usage. Instead, in the thesis 'straight forward gait' is defined as:

'That part of human locomotion that is linear (not rotational) and that advances the individual in the direction in which they are facing'

In this thesis, a new video-based research tool for the description of turning was developed and then used in a series of investigations to describe how people with and without PD turn to walk from a standing start. The aim was to gain a better understanding of dysfunctional turning in PD from which it would later be possible to develop management strategies with a sound rationale. Furthermore, were it possible to identify the characteristic parkinsonian turn, there may be potential to use that characteristic in supporting or refuting a diagnosis of PD. The content of each of chapter is summarised, below.

1.1 Thesis Structure

Chapter Two

The pathophysiology, signs, symptoms and motor impairments of PD are summarised, with an emphasis on the impairments of gait and balance. Issues relevant to understanding dysfunctional turning are introduced and the paucity of existing research highlighted. A need for further research is illustrated and hypotheses to be tested are proposed.

Chapter Three

The methods and tools that have been used by other researchers to evaluate turning are critically reviewed. As no existing tool was identified that was appropriate for use in the proposed studies, the development of a new tool, the Standing Start 180° Turn Test (SS-180), was necessary.

Chapter Four

The development of the SS-180, a tool intended to be used with people with PD beyond the laboratory setting, is discussed. The SS-180 requires participants to turn once in the direction of their choice and once when compelled to turn in the opposite direction. Participants begin the test standing with their backs to a target toward which they then turn and walk. The early steps taken to explore the external validity and reliability of the new tool are outlined.

Chapters Five to Seven

The studies undertaken to address the research questions and test the hypotheses proposed in Chapter Two are reported and the findings are discussed. The first studies conducted using the SS-180 (Chapters Five and Six) were conducted in a gait laboratory, a controlled environment where motion analysis equipment was utilised. The main study, in which the way people with PD and controls of similar ages turned was investigated, was conducted in the participant's homes (Chapter Seven).

- In Chapter Five (Movements used by Healthy Adults during the SSS-180), testing a convenience sample of healthy adults in the laboratory is discussed.

- In Chapter Six (A Preliminary, Laboratory-based, Investigation of how People with PD Perform the SS-180), the results of testing a small group of people with PD in the laboratory are discussed.

- In Chapter Seven (A Comparison of People with and Without PD Performing the SS-180), the main study, which was conducted at home to be inclusive of disabled people with PD and for reasons of ecological validity, is discussed.

Chapter Eight

Issues around the *exacerbation* of dysfunctional turning are explored, as people with PD have reported that certain circumstances amplify the difficulties that they experience.

- The people with PD who took part in the laboratory-based and home-based studies were asked a number of questions about turning; their responses are discussed in this chapter.

- The differences between turning in a freely chosen direction and turning when *compelled* to go in the other direction are considered here. The question of whether it is possible to predict who will have difficulty turning in a specified direction from the way that people with PD turn naturally is addressed.

Chapter Nine

In this final chapter, the work as a whole is discussed and the implications for research and practice are considered.

Chapter Two

Introduction

2.1 Overview of Chapter

Parkinson's Disease has featured in the literature since 1817, when James Parkinson wrote his essay on 'the shaking palsy'. The pathology was defined 100 years later and treatment revolutionised in the 1960's by the drug Levodopa. PD is caused by depletion of the neurotransmitter Dopamine within the Basal Ganglia (Section 2.2), eventually generating a range of motor signs and symptoms. Research on the cause has yet to produce a widely accepted theory but there is a consensus that the insult triggering the changes probably occurs many years before symptoms arise. Cell loss within the Substantia Nigra may be accelerated beyond the usual age-related rate of decline for perhaps 30 years before the individual with PD notices any motor difficulty.

The classic signs of PD are Bradykinesia, Rigidity, Resting Tremor and Postural Instability. Presentation varies tremendously and the disorder is difficult to diagnose accurately in the early stages. People with advanced PD characteristically demonstrate a narrow-based, festinating gait and a flexed, 'simian' posture in standing (although occasionally they adopt a backward-leaning erect stance). PD leads to difficulty with sequential and simultaneous movements, the former becoming increasingly disjointed and the latter being separated into the component actions. People with PD are often unable to make the desired movement at the desired time; movements become smaller and slower than necessary and difficult to initiate and terminate as required. Automatic movements are more impaired than voluntary movements. The ability to move can be facilitated by external stimuli such as visual cues: stepping over lines on the floor, or even imagining doing so, can help to initiate gait or increase stride length. Within the range of movement difficulties frequently encountered by people with PD, the one central to this thesis is dysfunctional turning. Uniquely among the neurological disorders, PD is highly amenable to drug therapy although the side effects can be very disabling. Medical management has been predominantly based on drug therapy since the 1960's and is aimed at replenishing the Dopamine level in the Basal Ganglia and reducing the relative increase in Acetylcholine. In comparison with straight-line gait turning has been little researched and remains relatively poorly understood and resistant to therapy: difficulty turning when standing or walking can be a significant problem, associated with freezing, falls and fractures (Section 2.3).

2.2 Parkinson's Disease

In 1978, Kessler estimated the prevalence of Parkinsonism as between 80 to 1,400 per 100,000 people. Broe and Creasy (1989) placed the prevalence of Parkinsonism lower than that of dementia and stroke but above that of epilepsy, central nervous system tumour and motor neurone disease. However, as McMahon (1990) cautioned, 'there are considerable difficulties in quantifying the exact prevalence of *[neurological diseases in the elderly]* in order to obtain a league table, since definitions and methods differ'. Mutch et al (1986) showed that the incidence and prevalence of PD rise with age, from 0.06% below the age of 60 to over 2% at the age of 80. They estimated the prevalence at 47 cases per 100,000 people aged 40 to 49, rising to 254 aged 60 to 69 and 1925 cases per 100,000 people aged 80 and over. In a district of 300,000 people, approximately 45 will develop the disease each year and 500 will have the disease at any one time (Marttilla, 1987): a GP with 2,000 patients might expect to have four with Parkinsonism. Three-quarters of people with PD are over 70 years of age and although the mean age at onset is 65, one case in seven is diagnosed before the age of 50 (Caird, 1991). Such early-onset PD is thought to differ in both presentation and the rate of progression to late-onset PD (Pantelatos and Fornadi, 1993).

2.2.1 The Basal Ganglia: Function and Pathology

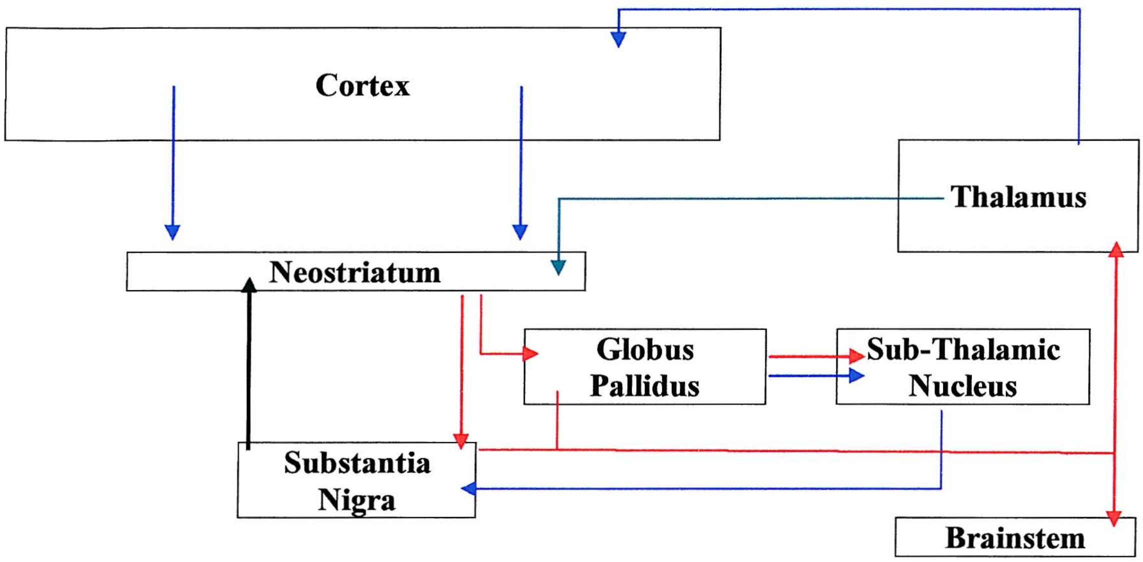
2.2.1a Function

To understand the effects of Dopamine depletion, it is necessary to understand the function of the Basal Ganglia, five main nuclei situated between the Cortex and the Thalamus:

1) **The Caudate Nucleus** and 2) **The Putamen** (together the Striatum)
3) **The Globus Pallidus** (external and internal nuclei, GPe and GPi)
4) **The Subthalamic Nucleus** (STN) and
5) **The Substantia Nigra** (Pars Reticulata and Pars Compacta, SNpR and SNpC)

The connections of the Basal Ganglia are summarised in **Figure 2.1**.

Figure 2.1. The Basal Ganglia: Transmitters and Major Connections



Grey boxes represent The Basal Ganglia and coloured boxes the important connecting structures. **Green Arrows** indicate Acetylcholine; **Black Arrows** Dopamine; **Red Arrows** GABA; **Blue Arrows** Glutamate. Based on Barker (2002).

The major input to the Basal Ganglia comes from the Cortex and the majority of the output goes back to the Cortex, via the Thalamus: output from the Basal Ganglia inhibits the activity of the Thalamus, reducing its output to the Cortex. The dopaminergic pathway arises from the SNpC and terminates in the Striatum, where Dopamine is released. Dopamine excites a direct (inhibitory) pathway and inhibits an indirect (excitatory) pathway. Inhibitory output neurones fire at a high rate even at rest, acting as a 'brake' to movement: when the brake is removed movement may occur. Excess inhibitory output from the Basal Ganglia causes a reduction in movement: animal experiments have confirmed that the inhibitory neurones fire excessively, so destruction of the GPi or the STN has been pursued therapeutically. Ordinarily, removal of Basal Ganglia output does not *cause* movement but *facilitates* movement; other excitatory inputs cause movement.

The Basal Ganglia are just one part of the total motor control system and their function must be considered in relation to the function of the whole. The 'fundamental task of the motor system' is to transform the idea of a required movement into the appropriate action (Rothwell, 1998). In health, movement is controlled by a combination of feedback control and programme control (Mak and Cole, 1991).

Motor programmes hold the basic characteristics of a movement, which can be modified to meet the specific demands of a situation. A motor act runs from receiving the stimulus to move, through the formulation of a motor programme to movement initiation, execution and termination (Marsden, 1984). The major motor pathways are a) the **pyramidal tract** (from the cortex to the spinal cord) that strongly influences neurones innervating distal muscles, b) the **reticulospinal tract**, projecting largely to the axial and proximal muscles and c) the **vestibulospinal tract**, again projecting largely to the axial and proximal muscles.

2.2.1 b Pathology

PD is a progressive neurological disorder caused by a loss of Dopamine-producing cells and depletion of the neurotransmitter Dopamine within the Basal Ganglia. Dopamine depletion causes a relative increase in the production of Acetylcholine and parkinsonian signs and symptoms arise when inhibitory and excitatory events in the Basal Ganglia are unbalanced. The pattern of cell loss characteristic of PD results from a specific pathogenic mechanism, unlike the cell loss associated with normal ageing. In PD, the loss of dopamine-containing neurones is greatest in the SNpC, with the degree of loss closely related to disease duration (Damier et al, 1999).

People with PD can select and formulate motor programmes prior to movement initiation. However, basal ganglia dysfunction may lead to delays in translating the motor programme into appropriate muscle activity. Bradykinesia may reflect the inability of people with PD to maximise their movement speed when they are required to *internally* generate the necessary drive. Majsak et al (1998) analysed the reaching movements of six people with PD and six controls as they reached for and grasped ('as fast as possible') a stationary ball and a ball rolling down an inclined ramp. Those with PD were bradykinetic when reaching for the stationary ball but not when reaching for the rolling ball. It appeared that the 'external driving stimulus' enabled them to exceed their internally generated speed while still maintaining accuracy comparable to that of the controls. These findings suggest that bradykinesia is not a result of insufficient force production or a compensatory mechanism for poor accuracy.

Akinesia may reflect impaired central processing and deficient motor planning (Rogers and Chan, 1988) although Jones et al (1993) demonstrated experimentally that people with PD did not 'appear to have problems reprogramming any specific movement parameter'. They discussed the possibility that the Basal Ganglia are not involved in the specification of movement parameters but have a higher level role, in conjunction with the Supplementary Motor Area (SMA). The pathological basis of rigidity may lie in an enhancement of the long-latency stretch reflex (Rothwell, 1994) as in people with Parkinsonism, this transcortical reflex (which can ordinarily be 'turned on or off' voluntarily) is enlarged, in proportion to the degree of rigidity. The nervous system has a natural tendency to oscillate and while physical and biochemical changes have been detected in the brains of people with tremor the precise changes attributable to tremor remain elusive. Extensive use of static and dynamic posturography has demonstrated the complex pathophysiology of postural instability in PD. Bloem et al (in press) summarised the factors thought to give rise to postural instability in PD:

1) Abnormally sized automatic postural responses in the lower legs
2) The 'inflexibility' of automatic postural responses
3) Altered activation sequence of automatic postural responses, with earlier than normal activation of proximal leg muscles
4) Delayed onset latencies of automatic postural responses
5) Delayed initiation of voluntary postural responses
6) Abnormal execution of compensatory stepping movements
7) Higher than normal background activity in leg and trunk muscles, and
8) A form of joint stiffness (rigidity, co-contraction or secondary changes)

Aetiology

The cause of the degeneration of the dopaminergic neurones projecting to the Striatum is not known, although several risk factors have been proposed. Hereditary susceptibility to an environmental toxin has been suggested (Barbeau et al, 1986) but not demonstrated convincingly. Barbeau et al proposed that the genetic abnormality that they identified among 40 people with PD reduced the ability to metabolise environmental toxins. Although a causative role in the aetiology of PD has been proposed for a number of diseases, evidence is lacking. PD is not caused by an infection.

Ageing may play a part in the development of PD and there is evidence to support a number of theories, including the susceptibility of the Substantia Nigra to free radical damage (McGeer et al, 1977; Calne et al, 1984). Although most people with PD are elderly, factors other than ageing must contribute: the age-specific incidence of PD declines after 75, monozygotic twins are not affected equally (Ward et al, 1983) and age-related motor dysfunction does not improve with Levodopa. Certain toxins (e.g. phenothiazines, manganese and carbon monoxide) have been shown to cause Parkinsonism but an agent causing PD has not been identified: a long latency between exposure and disease presentation is strongly suspected. The search for a likely toxin (or toxins) continues: the insecticide paraquat and water drawn from wells have both received attention but the findings were not convincing. Calne and Langston (1983) suggested that PD is caused by subclinical damage to the Basal Ganglia (following exposure to an environmental toxin) superimposed on age-related neuronal loss.

2.2.1 c The Classic Signs

Bradykinesia, rigidity, resting tremor and postural instability are the cardinal signs of PD. Bradykinesia implies that movements have become slow, absent or poor in quality, with repetitive movements gradually decreasing in amplitude. Rigidity occurs in the limbs and axially. It is characterised by increased tone in both the agonist and antagonist muscles and is thought to be a causal factor in the development of the characteristic stooped posture in PD. 'Lead Pipe' rigidity presents as smooth resistance to slow, passive movement, whilst 'Cog-wheel' rigidity probably reflects a superimposed tremor. Tremor describes any unwanted, rhythmic, approximately sinusoidal movement of a body part. A rest tremor is present when the limb is relaxed and fully supported and always suggests Parkinsonism. An action tremor arises when attempting to hold a posture or produce movement. More than 50% of people with PD do not have tremor. Postural instability tends to be a late symptom in PD, perhaps associated with a loss of the storage capacity for striatal dopamine, involvement of dopamine receptors, changes in nondopaminergic neurotransmission or axial bradykinesia, although it may occur much earlier and falls are occasionally the presenting symptom (Klawans and Topel, 1974). Gauthier and Gauthier (1983) correlated the signs and symptoms of PD with activities of daily living (ADL) and found postural instability to be the most significant cause of ADL impairment.

The unilateral onset of symptoms and the 'persistent asymmetry of signs' is characteristic of PD; symmetrical Parkinsonism suggests Progressive Supranuclear Palsy (SNP) or Multi System Atrophy (MSA) (MacPhee, 2001). Specific groups of signs appear to be differentially associated with prognosis and neurobiology (Bennett et al, 1999; Louis et al 1999): some researchers consider the presentation of PD to be either tremor-dominant or dominated by the other cardinal signs. Zetusky et al (1985) studied 374 people and identified one bradykinetic sub-group (with instability and gait difficulties) and another having predominantly tremor. Similarly, Koller et al (1989) found a dichotomy in their 100-strong sample; those with tremor formed one group whilst in another distinct group the other symptoms (including falling) clustered together. Nieuwboer et al (1998) also analysed the relationships between motor problems and symptoms. Again, certain symptom clusters were apparent, for example gait disorders and disorders of balance, posture, rising and rolling formed a cohesive grouping (as did turning, gait and falling, in keeping with an earlier finding by Lakke et al, 1982). Disordered axial rotation may arise from lesions in non-dopaminergic pathways as the symptom is only weakly related to more distal symptoms and resistant to the beneficial effects of levodopa therapy.

Diagnosis

Age-related disorders such as PD are an increasing problem in ageing populations and, as yet, diagnosis is only possible (and thus treatment only initiated) when the symptoms are manifest (Knoll, 1990). The cardinal signs of PD can be found among elderly people without PD and are frequently found among people with Alzheimer's Disease. The difficulty of diagnosing PD is well-recognised (Meara et al, 1999) and there is as yet no widely available screening or confirmatory test. The diagnosis remains a clinical one, based on the presence of bradykinesia and another cardinal sign, in the absence of exclusion criteria but with evidence of supportive criteria, as summarised in **Table 2.1**.

Table 2.1. The UK PD Society Brain Bank Three-step Diagnostic Procedure

1	**Diagnosis of parkinsonian syndrome**	Bradykinesia and at least one from: muscular rigidity 4-6 Hz resting tremor postural instability
2	**Exclusion criteria for PD**	Examples: history of repeated strokes or head injuries, negative response to levodopa.
3	**Supportive positive criteria for PD**	Examples: unilateral onset, progressive disorder, severe levodopa-induced chorea. *(three or more for diagnosis of definite PD).*

2.2.2 Disturbance of Motor Function in PD

All types of movement are impaired in PD, from those involved in postural control to fine digital movements.

As Bridgewater and Sharpe (1997) demonstrated, trunk muscle function is deficient in PD. Both a reduced range of spinal motion and decreased muscle power have been identified in people in the early stages of PD. Deficient trunk muscle function impacts on posture (many people with PD walk in marked postural flexion, looking down at the floor) balance control and cardio-pulmonary function. The typical flexed posture, which displaces the centre of gravity, compromises postural stability (although some authors (Bloem et al, in press) argue that a stooped posture protects against retropulsion and backward falls). Restricted movement of the head on the trunk altered the biomechanics of turning to a greater extent than it altered the biomechanics of straight forward gait (Hollands et al, 2000). Trunk muscle deficits may have central and/or peripheral causes.

Voluntary movement becomes progressively impoverished in PD, with particular difficulty initiating movement. People with PD have difficulty sequencing repetitive movements and the Basal Ganglia are suspected of a role in such movements, perhaps in motor timing. There is support for this theory. Freeman (1994) tested the ability of 34 people with PD and 36 controls to match finger-tapping frequencies with and without auditory cues. With low-frequency cues (1-3 Hz) the PD group tapped too fast and with high-frequency cues (4-5 Hz) the PD group tapped too slowly in comparison with controls; the abnormalities were exaggerated after cue cessation.

Cunnington et al (1995) studied SMA activity as people with PD performed sequential movements. The SMA was only involved in internally-determined movement, not when cues were given. The major input to the SMA is from the Basal Ganglia. Perhaps, with these connections impaired, the SMA was bypassed in the presence of external cues. SMA involvement was reliant on the presence of temporal cues, providing support for a role for the SMA and Basal Ganglia in the timing of sequential movement. Steiger et al (1996) attributed difficulty rolling to the inability to execute the required sequence of axial movements. They discussed the possibility that the pathology of PD differentially affects the 'postural' motor column arising from the supplementary motor area (influencing axial and postural muscles), see Chapter Three.

Simultaneous tasks too are challenging to people with PD. Morris et al (2000) tested the stability of 15 people with PD and a history of falls, 15 without and 15 healthy controls during steady standing and in response to perturbations, with and without a concurrent verbal task. They showed that a concurrent verbal-cognitive task impaired postural stability, putting fallers with PD at high risk of losing equilibrium because their initial balance control was already so poor.

Straight forward gait has been well described in PD. Purdon Martin (1967) observed that the parkinsonian gait was characterised by slowness, reduced step length, reduced or absent armswing, reduced trunk rotation, a stooped posture, reduced amplitude of hip, knee and ankle motion and decreased ground clearance. When attempting to initiate walking, people with PD often demonstrate aborted steps before their first complete step (Elble et al, 1996).

Recent work by Mesure et al (1999) has added to the picture of typical parkinsonian gait by demonstrating that people with the condition adopt 'a pattern of head stabilisation on the shoulder about the roll axis' and 'en bloc functioning of the head-shoulder unit'. Kemoun and Defebre (2001) have attributed the characteristic reductions in speed, step length and swing phase and increase in cadence (detailed below) to the 'incapacity to produce internal marks to generate regular steps'.

It has been suggested that 'the principle locomotor deficit *[in PD]* is an impaired generation of postural shifts that mediate changes from one steady-state posture or movement to another' (Elble et al, 1996). Koozekanani et al (1987) demonstrated that people with PD generated underscaled vertical and frontal ground reaction forces at push-off. Dietz et al (1995) showed the amplitude of Gastrocnemius EMG to be reduced in PD and, later, Morris et al (1999) demonstrated that the power generated by the ankle plantarflexors at push-off is underscaled in PD, with a, possibly compensatory, increase in hip flexor 'pull off' at early stance. Morris et al (2001) described Force Regulation as an 'emerging theme in the literature on straight line walking'. Burleigh-Jacobs et al (1997) suggested that dopaminergic pathways influence the force-production of self-generated step initiation. They demonstrated greater force production during the 'on' phase than the 'off'. Nieuwboer et al (1999) showed the flat-footed gait of people with PD required considerable energy expenditure and might increase the risk of tripping.

Gait velocity is reduced in PD [Murray et al, 1978; Morris et al, 1994 and 1996; O'Sullivan et al, 1998]. Murray et al studied 44 men with PD (mean age 61 years) and 24 controls walking at both free and fast pace. The former walked more slowly than the latter at both paces, particularly the 15 severely disabled participants, whose performance is summarised in **Table 2.2**. Morris et al (1994) studied 15 people with PD and 15 controls. The groups demonstrated similar gait velocities (95 and 91m/min, respectively) when asked to walk quickly over floor-markers, although the former walked more slowly than the latter without markers.

Table 2.2. Velocity, Step and Stride Length in People with and without PD: Examples from Murray et al (1978) and Morris et al (1994)

		Controls		**People with PD**	
		Free Pace	Fast Pace	Free Pace	Fast Pace
Gait Velocity: m/min	Murray et al*	84 (± 3)	112 (± 6)	40 (± 4)	58 (± 8)
	Morris et al	71	93	50	65
Step or Stride Length: m	Murray et al* *[step length]*	0.8 (± .02)	0.9 (± .03)	0.4 (± .04)	0.5 (± .05)
	Morris et al *[stride length]*	1.3	1.4	0.9	1.1

* Values are means (sem)

Differences in the mean stride length of people with and without PD have also been demonstrated (Murray et al, 1978; Morris et al, 1994; Hanakawa et al, 1999). Murray et al's controls increased step length when walking fast. As consciously walking fast induces (potentially beneficial) changes in the temporal and spatial parameters of gait, it is interesting to speculate what effects such a demand might have on the ability to turn. People with PD demonstrated shorter step lengths than the controls, particularly those with severe symptoms (see below). Step width and foot angle was similar in both groups. In Morris et al's study, the controls demonstrated greater stride lengths than did the PD group, at both preferred and fast speeds, although the groups demonstrated similar stride lengths (approximately 1.4m) when walking quickly over floor-markers. Later, Morris et al (1996) demonstrated that stride length could be temporarily increased by both visual cueing and mentally picturing the desired length. Hanakawa et al found the stride length of people with PD (0.3m) shorter than that of controls (0.4m) during treadmill walking at approximately 13m/min. Ebersbach et al (1999) hypothesised that the decreased stride length characteristic of PD helps to reduce energy expenditure. Among healthy adults, age and sex are key determinants of gait velocity and stride length but the degree of disability is probably a more important determinant in PD. Murray et al's exclusively male sample was younger than that of Morris et al and walked faster. Morris et al's predominantly mildly disabled PD group walked faster than did Murray et al's predominantly severely disabled group.

People with and without PD have demonstrated a similar cadence, i.e. steps per minute (Murray et al, 1978; O'Sullivan et al, 1998). Hanakawa et al (1999) however, found cadence on a treadmill to differ between people with and without PD (103 and 71, respectively). Using Single Photon Emission Computed Tomography (SPECT), Hanakawa et al (1999) proposed that brain activity during gait differed between people with and without PD. Some scans require a still head, so cannot be used for tasks accompanied by gross body movements. With SPECT, however, an injected tracer is rapidly distributed to the brain (in proportion to blood flow), trapped within minutes and remains stable for hours, providing a snapshot of brain activity in someone moving freely. The investigators compared ten people with mild PD (mean age 67 years, mean disease duration seven years) with controls. In comparison with the controls, specific areas of the brains of people with PD were overactive and some underactive.

Hanakawa et al interpreted their findings cautiously. They acknowledged that treadmill and off-treadmill walking are very different activities and questioned the functional significance of their data. The similarities and differences in brain activity between people with and without PD warrant further investigation: overactivity and/or underactivity might explain gait hypokinesia.

Rotational gait (turning) is the focus Chapter Three but it must be mentioned here in relation to gait as a whole. The typically festinating gait is characterised by the inability to maintain the base of support beneath the forward moving trunk (Bloem et al, in press). To ensure postural stability and prevent falls, individuals seek to avoid a potentially destabilising perturbation in the first place, using strategies that include modulating foot placement, increased ground clearance, 'steering' and stopping (Patla, 1996). The Basal Ganglia play an important part in these mechanisms. When turning (or 'steering' the body is allowed to fall to the desired side over a suitably placed foot; Purdon Martin, 1967). Turning while maintaining balance and momentum is 'extremely complex' Hase and Stein (1999) and Morris et al (2001) considered that, when turning, stability was maintained at the cost of efficiency. Imai et al (2001) showed that, during turning, orientating mechanisms were operative that were not operative during straight forward gait. Some authors (Hase and Stein, 1999; Thigpen et al, 2000) consider different types of turn more stable than others and the selection of turn type a 'developmental change' in response to 'subtle changes in balance'. Charlett et al (1998) proposed that increased base breadth might stabilise straight forward gait but add to the difficulty of turning. If stability is lost, certain falls carry a particularly high risk of hip fracture because of the biomechanics of the fall, i.e. the direction, the point of contact with the ground and the force of that contact. Once again, people with Basal Ganglia deficits are unlikely to be able to respond to such a challenge by modifying their fall to reduce the likelihood of injury.

2.2.3 Movement Facilitation: Therapy and External Stimuli

In the early 1960's, studies revealed that the urinary excretion of Dopamine of people with PD was lower than that of controls and that (post-mortem) the Dopamine content of the Striatum was lower in the former than the latter. These discoveries led to the treatment of PD with Levodopa infusions, hoping to replace the missing Dopamine.

Levodopa is an amino acid able to cross the blood-brain barrier and be converted (decarboxylated) to dopamine. By the late 1960's, the oral administration of larger doses of Dopamine led to the beneficial effects becoming more constant and the role of Levodopa became established in large trials. Further developments revolved around the addition of a decarboxylase inhibitor (Benserazide) to block the conversion of Levodopa to Dopamine. Benserazide enhanced the rise of Dopamine following Levodopa administration, because its action is largely outside the brain, where it prevents Levodopa being decarboxylated before it can enter target areas. The combined Levodopa with Benserazide therapy allowed beneficial results to be achieved at a lower dose of Levodopa and with less adverse side effects.

Future developments in drug therapy for PD include minimising fluctuations (and side effects) by stabilising blood levels of Levodopa, inhibiting Dopamine breakdown by (Mono-amine Oxidase), thereby increasing the effect and duration of the neurotransmitter and interfering with alternative paths of Levodopa metabolism, so making more available to the brain. Despite the best pharmacological treatment, many people continue to experience increasing functional impairment as the disease progresses. Within a few years of starting Levodopa therapy, most people experience a shortening of the duration of action and fluctuations in motor response (Chase et al, 1990). Motor fluctuations begin in temporal relation to Levodopa ingestion, then later more complex variations (known as 'on-offs') appear. These dramatic shifts from under- to over-treatment can be considerably disabling. Researchers conducting movement analyses with people with PD must take the drug-related motor fluctuations into account when designing studies:

- Changes in the parameters of interest (e.g. stride length) throughout the drug cycle must be established.
- The sensitivity of the instruments used to measure change must be established.
- Data must either be collected at the same point in the drug cycle for every participant in cross-sectional studies, and/or
- Repeated assessments must be taken at the same point in the drug cycle in longitudinal studies.

In contrast to tremor and rigidity, disorders such as axial bradykinesia and postural instability may be among the symptoms of PD most resistant to Dopamine-replacement therapy. This discrepancy suggests that non-dopaminergic systems may contribute to these impairments. Falls are little reduced by current drug therapy (Sabin, 1982; Koller et al, 1989). Weinrich et al (1988) sought to understand whether Levodopa administration affected axial movements ('head rotation') and distal movements ('wrist flexion-extension') similarly. Twenty-eight people with PD (recruited through a local support group) were recorded before and after medication, performing each movement following a standard protocol. After Levodopa, there was an increase in the mean peak velocity of wrist movement but a decrease in mean amplitude and velocity of head movement among those with moderate to severe PD. Though it remains unclear 'why postural instability is the only major sign that is resistant to dopaminergic therapy' (Koller et al, 1989), the decline in axial velocity after Levodopa may go some way to explaining why postural instability is poorly ameliorated by drug therapy. Physiotherapy researchers have presented some encouraging findings with respect to reducing the frequency of falls. Yekutiel (1993) presented the cases of two people with PD who fell frequently. A 60-year-old woman, diagnosed 20 years, fell approximately 10 times a day in the four weeks preceding a trial of physical therapy. Reviewing her 'fall-diary', it emerged that she had particular problems steering round furniture and corners. Therapy was devoted to freeing her from the mental restrictions imposed on her by such hazards (for example, perceiving a corner as a continuous curved trajectory rather than as two lines at right angles) and her mean daily falls reduced to six. A 64-year-old man, diagnosed ten years, fell a mean 14 times a day in the two weeks preceding the trial; habitually near his armchair, in or near the kitchen and at the foot of the bed. Falls showed a tendency to decline during six weeks of therapy (tailored to the situations and circumstances surrounding the falls described in his diary) averaging ten per day.

Unfortunately, the role of non-drug treatments in PD remains contentious. In the case of physiotherapy, attempts to provide objective evidence have resulted in conflicting opinions and general exercise has been considered as beneficial as any other advice. As Weiner and Singer (two physicians) stated in 1989, 'current societal thinking regarding physical activity as good' has guided the management of PD. They went on to suggest that while 'the specifics of *[a physiotherapy]* program are not important', the psychological benefits (such as increasing motivation) may be.

In 1986, Mutch et al called for 'long term, multicentre, controlled studies' to evaluate the most appropriate, cost effective ways to use the skills of therapists and improve the quality of life of patients with PD: such studies remain to be completed. The role of physiotherapy or exercise in PD has been investigated but many reports have been anecdotal, without statistical support, lacked control subjects, did not compare treatment regimes or have not capped the activity of controls. Kinnear (1986) argued for early referral to physiotherapists, before the development of 'abnormal postures and patterns of movement'. She stated that treatment ('whichever methods are used') should be aimed at 'solving problems the patient is having at the time': in the case of difficulty turning, therapists do not know what is 'normal', let alone how to correct the 'abnormality'. Evidence is gathering: a meta-analysis of studies evaluating physical therapy in PD concluded that patients do benefit from physical therapy added to their antiparkinsonian medication (De Goede et al, 2001). Drug therapy alone does not address the range of motor problems found in PD and while evidence in support of specific physical interventions is lacking, physicians will remain reluctant to refer to physiotherapists. A recent Cochrane Review concluded that there was 'insufficient evidence to support or refute the efficacy of physiotherapy' in PD: although difficulty turning is common, therapists can offer little intervention of demonstrable efficacy.

One aspect of physiotherapy that has received considerable interest from researchers is the use of external stimuli or cues to facilitate movement. While certain stimuli have been shown to promote movement (illustrating the coordination between the Basal Ganglia and other parts of the motor control system) other stimuli have been shown to impede movement.

External Stimuli

Morris et al (1994, 1996) concluded that the regulation of stride length was the key deficit underlying hypokinesia and the characteristic gait of PD and that increased cadence was a compensation for reduced stride length. They showed that people with PD can increase speed, cadence and step length when stimulated with external cues.
It is important to contrast the difference between the hazard-free laboratory environments in which cues have been found effective with the 'real world' environment where the application of cues may be less practical.

Nearby features seen in the peripheral vision can capture attention and *impair* movement, which may be why doorways are a common cause of freezing. McDowell (1995) demonstrated that transient visual distractors impeded movement among people with PD but not controls. As Patla (1996) stated, the Basal Ganglia free the nervous system from being 'a slave to external stimuli'.

Whilst the subconscious, automatic basis of movement is evidently lost in PD, some movement abnormalities can be temporarily overcome by voluntary effort. It has been shown repeatedly that movement is facilitated by certain external stimuli: the beneficial effects of auditory and visual cues have been widely reported (including Martin, 1967; Flowers, 1976; Cooke et al, 1978; Stern et al, 1983; Eni, 1988; Bagley et al, 1991). Eni measured differences in knee flexion (in eight subjects) when walking with and without Bach's 'Sleepers Awake' playing and suggested that the music might have induced relaxation or established rhythmic responses, either of which may have improved the quality of gait. Bagley et al examined the effect of visual cues on the kinematics of gait of ten people with mild to moderate gait disturbance as a result of PD. The response to cueing varied markedly between subjects. Changes in some parameters when gait was cued were attributed to the cues but the roles of the equipment, medication and the subjects must be considered: only certain spatial parameters showed any carry-over effect minutes later. Verbal cues, too, have been shown to beneficially alter the gait parameters of people with PD. Behrman et al (1998) found that four different sets of verbal instructions (e.g. "swing arms", "count") led to changes in step length and walking speed. The authors emphasised that cues found to be useful during straight forward gait might be markedly less beneficial when turning or negotiating corners. Yekutiel et al (1991) claimed that successful physiotherapy in PD ('restoring whole-body movement') depended on the intellect, making explicit what is ordinarily automatic.

The majority of the investigations that have examined the spatiotemporal, kinematic or kinetic parameters of gait 'have been conducted in laboratory or ward settings' (Morris et al, 2001). They have revealed that people with PD hesitate when initiating gait and walk slowly, with a high cadence and short stride length. Any or all of these factors might contribute to the increased risk of falling that is associated with a diagnosis of PD and the focus of the remainder of this chapter.

2.3 Turning, Freezing, Falls and Fractures

While straight forward gait has been well described, with consistent findings reported in numerous studies, relatively little is known about turning, although difficulty turning is a widely acknowledged problem in PD. Though little data has been collected systematically, it appears that dysfunction is exacerbated by demands such turning quickly, turning in confined spaces and, in some cases, turning in particular directions (Ashburn et al, 2001b; Stack and Ashburn 1999). Even individuals whose symptoms are well-controlled by medication and who can walk well in straight lines may experience difficulty turning, particularly when challenged by additional demands. In 1998, Nieuwboer et al evaluated the ability of 60 out-patients with PD to turn in a confined space using criteria proposed by Tinetti (1986): approximately half of the sample demonstrated difficulty and reported it to be a frequent problem. Bloem et al (2001) identified difficulty turning among 35 of the 58 out-patients with PD they assessed (62%) in comparison with just two of the 55 partners assessed (4%). Further support for the notion that turning is a more common cause of falls in PD than among elderly people in general comes from Wild et al (1981). They found turning to be the fall-related activity in only five of the 125 falls described to them by elderly people and Berg et al (1997) found turning to be the fall-related activity in only 7% of the falls described to them.

2.3.1 Freezing or Motor Block

Motor Blocks, sudden, short duration breaks in motion and inhibition when executing movement or switching between movements, are common in PD and frequently described as 'freezing'. Giladi et al (1992) surveyed almost 1000 people with PD and found 'start hesitation' the most common motor block (reported by 86% of the respondents having freezing episodes) followed by motor block during turning (reported by 45%). They suggested that the underlying cause was the abnormal retrieval or use of motor programs.

2.3.2 Falls

Whilst one in three elderly people fall in any year (Campbell et al, 1989; Tinetti et al, 1988) recent estimates suggest that the proportion of people with PD falling is twice as high (Paulson et al, 1986; Stack and Ashburn, 1999; Ashburn et al, 2001). Multiple falls are associated with increased mortality, as they may mark underlying diseases and disabilities that increase the risk of death (Dunn et al, 1992) and falling is a common cause of accidental death among elderly people (Sattin, 1992; the Department of Trade and Industry, 1993). In this section, an overview of the causes of falling in old age and PD is presented, with the emphasis on fall-related activities, particularly turning.

2.3.2 a Risk Factors for Falling

A 1996 Effective Health Care Bulletin summarised some of the most frequently cited risk factors for falls among elderly people as shown in **Table 2.3**. Examples of risk factors related to gait abnormalities include:

1) Fallers walk more slowly with a shorter stride than non-fallers (Wolfson et al, 1990).
2) Fallers mean heel width is 13% greater than non-fallers during 6km/h treadmill walking (Gehlsen & Whaley, 1990).
3) 'Abnormal stepping' was a factor in a fall-predictive model (Clark et al, 1993).

Table 2.3. Summary: Risk Factors for Falling (Effective Healthcare, 1996)

Nutritional Status	Environmental Hazards	Lack of Exercise	Medication	Ageing Changes & Medical Condition
Vitamin D & Calcium deficiency	Loose carpets, poor lighting & Ill-fitting shoes	Weakness, poor balance & gait, bone loss	Antidepressants, Hypnotics, Diuretics	Visual impairment, cognitive impairment

A diagnosis of PD is itself a risk factor for falling. Nevitt et al (1989) found PD to be a factor predictive of multiple falls. For one year, Northridge et al (1996) followed a cohort of 325 community-dwelling previous fallers aged 60 years or older. They found PD to be predictive of falls at home not involving hazards, with an adjusted odds ratio of 7.7 (95% CI 1.2-51.1).

There are many reasons why people with PD fall, for example:

1) Spinal flexibility, which contributes to dynamic balance control, is often restricted in people with PD (Schenkman et al, 2000).
2) The gait speed and stride length of moderately disabled people with PD shows 'marked deterioration' under conditions of increasing difficulty, from walking freely to carrying empty and loaded trays (Bond and Morris, 2000).

However, not every risk factor identified among elderly fallers applies in PD: e.g. Orthostatic Hypotension has been found in very small proportions of fallers and non-fallers with PD (Koller et al, 1989; Ashburn et al, 2001). Likewise, Pastor et al (1993) showed that the postural responses induced by vestibular stimulation were similar in 15 people with and ten without PD.

Aita (1982) summarised the factors that cause people with PD to fall as follows: 1) Sitting or Rising (when symptoms prevent natural movement), 2) Orthostatic Hypotension, which has many causes, and 3) Gait Abnormalities. Charlett et al (1997) investigated the prevalence of five 'intrinsic mechanisms' of falling among a sample of 25 elderly, newly diagnosed people with untreated PD. The 13 who had fallen since diagnosis demonstrated *inadequate protective reflexes* (having a longer reaction time than the non-fallers), *abnormal posture* (more fallers were 'stooped') and *greater postural sway*. Two of the 'mechanisms', rigidity and hypotension, were no more prevalent among the fallers than non-fallers. Both Koller et al (1989) and Ashburn et al (2001a) identified a number of differences between fallers and non-fallers with PD relating to gait, posture, balance and disease severity (see **Table 2.4**).

Table 2.4. Disease Severity between Fallers and Non-fallers with PD: Examples from Koller et al (1989) and Ashburn et al (2001)

	Koller et al			**Ashburn et al**		
	38 Fallers	62 Non-fallers	P Value	40 Fallers	23 Non-fallers	P Value
H&Y	Mean 3.0	Mean 1.9	0.0001	Median III	Median II	0.001 *[X^2]*
UPD	Mean 15.7	Mean 9.6	0.001	Median 22	Median 15	<0.0005 *[Mann-Whitney]*

H&Y = Hoehn and Yahr Grade; UPD = Unified Parkinson's Disease Rating Scale

Koller et al did not specify which statistical tests were used to compare groups. Their sample (61% men) had a mean age of 67 years, and median Hoehn &Yahr Grade II: Ashburn et al's sample (52% men) was slightly older (mean age 71) and more severe (median Grade III). Both studies were retrospective, so no causal link between any of the factors and falling was established. Ashburn et al studied a sub-sample in a gait laboratory. Compared with 19 non-fallers, the 29 fallers took a median of four more steps during the 'Get Up and Go' test, functional reach was a median 5cm shorter and postural sway in standing was greater when they were distracted by a competing cognitive task.

Horak et al (1992) found that the sway area of people with PD was smaller than that of controls, potentially a compensation for inadequate postural control. Responding to horizontal surface displacement, their PD group was 'stiffer' than the controls and their responses inadequate. The former did not modify their responses when the support conditions changed (to sitting or standing on a beam): they persistently activated every recorded trunk and leg agonist. The authors concluded that the postural responses of people with PD were 'inflexible' and dyscoordinated, though the sample was very small (eight people with PD and ten healthy adults).

2.3.2 b Fall-related Activities

The 1996 Effective Health Care summary is a concise depiction of the hundreds of factors thought to play a part in causing falls. However, the causative agent operative at the instant at which the fall happens is omitted. Arguably, risk factors act on an individual *all-day-every-day* but elderly people do not fall *all-day-every-day*. What causes the occasional fall to arise when it does? Arguably, the fall-related activity is the key part of the fall-precipitating circumstances, so investigators must explore the interaction of the faller with his or her environment to suggest why a faller fell *when* he or she did. Berg et al (1997) wrote that 'relatively little research has addressed what fallers are actually doing at the time of a fall, especially among older adults living in the community. This information is crucial for understanding the aetiology of falls as well as for effective clinical assessment and design of preventive strategies'. However, several investigators have published on the topic and relevant studies are summarised in **Table 2.5**. In each case, the outcomes of interest included fall-related activities and/or implicated hazards.

Table 2.5. Summary of Research on Fall-related Activities

Study		Setting	Sample
Ashley et al	1977	Care Unit.	400+ residents, 651 falls.
Wild et al	1981	Community.	125 falls.
Morse et al	1985	Hospital.	500+ in-patient fallers, 774 falls.
Gehlsen & Whaley	1990	Community.	25 healthy volunteers.
Campbell et al	1990	Community.	700+ people, 507 falls.
Speechley & Tinetti	1991	Community.	300+ fallers.
Lipsitz et al	1991	Nursing Home.	70 fallers.
Erasmus Fleming & Pendergast	1993	Adult Care	95 residents, 294 falls.
Northridge et al	1995	Community	300+ fallers, 252 falls.
Berg et al	1997	Community	50 fallers.
Norton	1997	Mixed.	
Sattin et al	1998	Community	270 fallers

In many studies, and in clinical practice, data on the activity in which the faller was engaged at the time of falling is often less complete than other circumstantial detail, e.g. only 29% of the falls described by Ashley et al mentioned the fall-related activity. The person documenting the fall may not have witnessed it: Morse et al (1985) found that staff witnessed only 23% of in-patient falls, visitors and other patients, only 6%. While a witness can easily record the location in which the faller was found, the time and evident injuries, they can only surmise what had happened. Similarly, unless asked specifically, fallers may be more inclined to recall some aspects of a fall than others (Stack and Ashburn, 1999). Authors may have considered the fall-related activities less significant than other aspects and not presented data that had been collected. Erasmus Fleming and Pendergast attributed the *primary cause* of falling to the faller's activity in only 8% of the falls that they surveyed and presented activity data on just those 8%. In the body of literature as a whole, fall-related activities are somewhat intermingled with other fall-precipitating factors (legs giving way and tripping over a step, for example). However, a picture of the activities during which elderly people fall most frequently is emerging.

In the studies conducted in adult care facilities the fall-related activities identified reflect frailty: falls transferring to or from the toilet or commode, during position changes such as getting out of bed and when using walking aids predominate. Walking is cited frequently.

Among community-based samples and samples of healthy volunteers the fall-related activities identified are frequently less to do with position change than they are to do with walking (the most frequently documented activity) and other high-level functions. Tripping and slipping, presumably during walking, frequently appear as fall-precipitating factors, as does misplaced stepping (e.g. into a hole). Loss of balance during activity has been cited frequently. Falls when turning, bathing or showering, crossing uneven ground, working outdoors, carrying objects, climbing stairs, reaching or standing on a chair (high level activities) are mentioned less frequently. Low-level activities (such as rising from bed) are associated with a small proportion of falls in community-samples.

The studies listed above highlighted the causes to which elderly people attribute falls, including moving too quickly, hurrying, 'not looking', slippery surfaces and tripping. Environmental hazards (steps and stairs, flooring, uneven paths, walking aids, dark or dimly lit environments, clothes and shoes, clutter and furniture) have been well documented in many studies. Their importance is debatable: Norton implicated them in only a quarter of falls at home, Sattin et al in only a fifth. Hazards are more frequently implicated in (and more predictive of) falls among vigorous rather than frail elderly people (Speechley and Tinetti, 1991; Northridge et al, 1995). Although Koller et al (1989) asked 100 people with PD to complete 'a detailed questionnaire' about falls, they omitted to include it in their paper and reported the accounts of the 38 fallers very superficially. The only information given was that falls 'occurred in a variety of circumstances, unrelated to the time of day, place or intercurrent activity. Environmentally caused slips and trips appeared not to be a common cause of falling'. Stack and Ashburn (1999) reported the circumstances surrounding the falls and near-misses reported by a community-dwelling sample of people with PD (Mean age 72 years and time since diagnosis four years). Among the activities in which the respondent was engaged at the time of the event, turning was highlighted twice as many times as the second most common group of fall-related activities, reaching and carrying; one respondent described turning as "fatal". Researchers have shown that fallers turn differently to non-fallers, for example, in the number of steps taken to turn on-the-spot (Lipsitz et al, 1991): these differences are discussed in Chapter Three.

2.3.2 c Interpreting the Research

Interpreting research on falling requires caution because all studies will have relied to some extent on the testimony of fallers or witnesses and some fallers deny having fallen. Accuracy of recall has long been cited as a limitation of published research.
For example, Wild et al (1981) claimed that 'fallers are rarely sufficiently aware of what happened or sufficiently articulate in their description to provide doctors with the necessary information'. It is acknowledged that falls are under-reported but the fabrication of accounts would be more of a concern to researchers seeking to identify the most common fall-related activities. More falls appear to be 'forgotten' than unconfirmed falls 'remembered' (see **Table 2.6**).

Table 2.6. Recall at Follow-up of Falls within the Preceding 12 Months: Examples from Cummings et al (1988) and Hale et al (1993)

Study	Recall Period	Fallers* who Recalled Falling		Non-fallers* who Recalled Falling
	Preceding -			
Cummings et al	12 months	87%		7%
	6 months	74%		6%
	3 months	68%		6%
		Fallers* who Recalled Falling	**Falls Recalled**	**Unreported-falls Recalled**
	Preceding -			
Hale et al	12 months	89%	48 / 56 (86%)	3
	6 months	44%	14 / 32 (44%)	3
	3 months	31%	7 / 17 (41%)	2

* Fallers - participants who had reported falling (via weekly postcards) *during* the study:
Non-fallers - participants who had not reported falling *during* the study.

In Cummings et al's one-year, prospective study (which involved approximately 300 elderly people), weekly postcards notified the investigators of any falls. At the end of the year, interviews revealed the proportions of fallers and hitherto supposed non-fallers who recalled falling (87% and 7%, respectively). Under-reporting was most evident when participants were asked about falls within three months, with unfounded recall of falls much less obvious. Hale et al produced similar results from a smaller study (approximately 100 elderly people).

Additionally, they found that only ten of 56 reported falls were documented in the family practitioners records, as were three 'unreported' falls! They concluded that patients recalled most falls but that their doctors were not aware of, or failed to document, them.

Some fallers may not consider that they have fallen, rather that they have tripped or slipped. This distinction is propagated in the media, e.g. legal advertisements ask 'Have you *tripped or fallen*?' Health professionals, too, use language that removes events from the umbrella term 'fall', e.g. 'Incidents which resulted in a patient *slipping or falling* to the floor were recorded' (Barrett and Swan, 1999).

2.3.3 Fractures

Having considered the causes of falls (and the importance of fall-related activities, including turning) it is important to consider one serious consequence of falling, fracture, and again the significance of turning. Falling while turning or reaching has been shown to carry an increased risk of minor injury (versus no injury) by Nevitt et al (1991). In a one-year follow-up of 325 elderly fallers, the adjusted odds ratio for sustaining minor injury during such falls was 3.5 (95% CI 1.7-7.3), greater than that of sustaining minor injury falling on stairs and steps (2.2; 95% CI 1.0-5.0). Unfortunately, researchers have not correlated the fall-related activity with the direction of falling and hence landing: Stack and Ashburn (1999), for example, reported *activity* and *landing* in isolation. Falls that occur during turning are likely to carry a high risk of hip fracture, one of the most costly and debilitating consequences of falling. Although relatively few falls result in such injuries, Boonen et al (1996) argued that falls causing hip fracture differ qualitatively from other falls and should be a research priority.

Cummings and Nevitt (1989) proposed that the interaction of the four factors summarised below (in **Table 2.7**) determined the likelihood of hip fracture: people with PD falling during turning would be subject to all four.

Table 2.7. Cummings and Nevitt Hypothesis (1989):
Factors Determining the Likelihood of Hip Fracture on Falling

Factor		**Hypothesis**
Faller Orientation	-	Moving slowly, with little forward momentum, a fall would result in direct application of impact energy to the femur.
Protective responses	-	The ability to grab something or stumble might prevent a fall, change the orientation of the faller or dissipate impact energy.
Local shock absorption	-	Muscle or fat around the hip would be protective, whereas a hard landing surface would increase the risk of fracture.
Bone strength	-	A number of disorders would weaken the bone around the hip and increase the risk of fracture.

After two years of following more than 9000 elderly women, Kelsey et al (1992) identified differences between the 171 women who sustained distal forearm fractures and the 79 who sustained a fracture of the proximal humerus. The former injury tended to occur in women who were 'relatively healthy', with good neuromuscular function, while the latter injury occurred in women who were 'less healthy and active'. Nevitt et al (1993) provided further evidence that the 'nature of the fall determines the type of fracture'. They interviewed elderly women who fell and sustained hip fractures (n=130), wrist fractures (n = 294) or no fractures (n = 467). Those who sustained hip fractures were more likely than those without fractures to have fallen 'sideways or straight down,' with an odds ratio of 3.3 (95% CI 2.0-5.6). Among those who 'fell on the hip', those who sustained hip fractures were less likely than those without fractures to have broken the fall by grabbing or hitting something (odds ratio 0.4; 95% CI 0.2-0.9). Those who sustained wrist fractures were more likely than those without fractures to have fallen backward, with an odds ratio of 2.2 (95% CI 1.3-3.8).

Later, Cummings and Nevitt (1994) presented a number of case-control studies that strengthened their assertion that the type of fall is the determinant of whether or not hip fracture occurs. In a cohort study that involved following 9000+ women (of whom 192 had hip fractures), Cummings et al (1995) identified several risk factors specifically for first fractures of the hip in elderly white women, many of which are modifiable.

Factors identified included maternal history of hip fracture, previous fracture after the age of 50, fair or poor self-rated health, the use of long-acting benzodiazepines, high caffeine intake, inability to rise from sitting without using the arms and poor contrast sensitivity. Women with five or more risk factors and low bone density were at particularly high risk. Seeley et al (1996) reported different profiles of risk factors for fractures of the ankle and foot in elderly women. For example, previous falls and vigorous physical activity were risk factors for ankle fracture, whilst insulin-dependent diabetes and poor far depth perception were risk factors for a fracture of the foot.

A diagnosis of PD appears to be a risk factor for sustaining a hip fracture. Koller (1989) described 38 fallers with PD, of whom 13 had sustained fall-related fractures (including four hips). In a case-control study, Grisso et al (1991) identified five factors that increased the risk of hip fracture: lower limb dysfunction, previous stroke, visual impairment, using long-acting barbiturates and a diagnosis of PD. The risk associated with PD (9.4) was the highest of all the factors. Johnell et al (1992) completed a retrospective cohort study with 138 people with PD and controls. Over the follow-up period, they found that the relative risk of any fracture in the PD group was double that of the controls. The greatest increase in risk was in the proximal femur: by ten years post-diagnosis, 27% of the PD group had sustained a new hip fracture. Taggart and Crawford (1995) compared 29 women and 26 men with PD with controls. The *total hip* and *neck of femur* Bone Mineral Density (BMD) were lower in the PD group than in the controls although that of the lumbar spine was similar. The authors contested that low BMD contributed (alongside the tendency to fall backwards or sideways) to the excess of hip fractures in PD. Poor mechanical loading was proposed as a cause of low BMD.

The pattern of fractures in PD suggests that the increased risk is due to specific types of falls rather than disuse osteoporosis (Johnell et al, 1992). Wrist fractures, commonly fall-related, were not excessive among the people with PD that Johnell et al studied, neither were vertebral fractures (closely associated with osteoporosis) but proximal humerus, pelvis and hip fractures, perhaps associated with falling backwards or sideways, were excessive. Physiotherapy does not often feature in the management of PD until a patient has reached an advanced stage or fallen and sustained a hip fracture (Schenkman et al, 1989).

The adverse consequences of falling reach far beyond physical injury. Some fallers develop a marked, even phobic, fear of falling, limiting their mobility and independence and increasing the risk of falling again (Bhala et al, 1982; Vellas et al, 1987; Vellas et al, 1997). Liddle and Gilleard (1995) illustrated that an enduring fear of falling can effect carers, too. They interviewed fallers and their carers on admission to hospital after falling and one month post-discharge. The proportion of carers expressing a fear of falling was higher at the second interview (see **Table 2.8**): the authors did not raise the issue of drop-outs at follow-up but they must be considered.

Table 2.8. Fallers and Carers Expressing Fear of Further Falls (from Liddle and Gilleard (1995).

	On Admission		**One Month Post-discharge**	
	Fallers (n = 69)	Carers (n = 42)	Fallers (n = 46)	Carers (n = 38)
Expressing Fear	17 (25%)	24 (58%)	9 (19%)	25 (66%)

Turning is clearly an important cause of activity-related falls and turning-falls are the type of fall likely to cause serious injury among a vulnerable group of people, yet this important aspect of functional mobility has been inadequately researched, to date. In Chapter Three, the research that has been published is reviewed.

2.4 The Need for Further Research

The issues covered in this introductory chapter can be summarised as follows. PD is a progressive neurological disorder, of uncertain cause, eventually presenting as a wide range of extrapyramidal motor signs (classically Bradykinesia, Rigidity, Resting Tremor and Postural Instability) and symptoms, in particular difficulty with sequential and simultaneous movements. Among the movement difficulties encountered by people with PD, the impairment of straight forward gait has been well described but difficulty turning (associated with freezing, falls and fractures) has been little researched and remains relatively poorly understood and resistant to therapy. 'One argument for expanding resources for fall prevention is that even greater resources will be saved through fewer hospitalisations and other health services' (Tinetti, 1994).

Understanding the way in which the faller interacts with the (potentially hazardous) environment should allow the destabilising interaction (the fall-related activity) to be modified, affording the faller safer function without compromising his or her independence. Lipsitz et al (1991) stated that researchers had not yet addressed 'the complex interactions between multiple host and environmental factors that contribute to falls in different ways in different groups of elderly people'.

To improve the management of dysfunctional turning there is a need to understand more about the impairment. For example, parkinsonian turning may be, like gait, characteristically slow, with a high cadence and short step length. It may be that slow, high cadence, short stepping turns put the turner at risk of falling: conversely, such turns may represent successful compensation for perceived postural instability. Bloem et al (in press) described the development of compensatory strategies to cope with a disorder of postural instability as the most important confounding factor in the interpretation of balance abnormality and highlighted the need to distinguish beneficial compensatory strategies (usefully stimulated) from maladaptive processes (to be discouraged). As Bagley et al (1991) stated, 'the actual role of physiotherapy (in the management of PD) has never been firmly established. Techniques such as encouraging reciprocal arm swing to improve the quality of walking are, they suggested, unlikely to 'produce anything except a short-term effect'. If therapists are better aware of the determinants of fall-related activities such as turning, they should be able to develop interventions with a sound rationale. Rather than trying to 'normalise' the appearance of an activity, promoting the modifications found useful by people with difficulty turning (e.g. slowing down, choosing a preferred direction, taking small steps) might be more appropriate.

There is a clear need for further research on the impairment of turning associated with PD because the majority of studies completed to date have excluded people with PD and generated few findings of relevance to people with PD because of the designs deployed. In this thesis, I attempt to answer some of the outstanding questions. The movements demonstrated during standing start 180° turns by healthy adults will be described in an early laboratory study (see Chapter Five) and the influence of age and balance control on the performance of turning explored. Differences in how people with PD turn spontaneously in a freely chosen direction will be described in another laboratory study (see Chapter Six).

2.4.1 Hypotheses to be Tested

Primary Hypothesis

- Turning is a highly balance-demanding activity and the physical abilities required to turn (balance control, range of motion, speed of movement and the ability to perform symmetrical, discordant, bilateral movements) are all impaired in PD so people with PD have to demonstrate compensatory turning strategies.

Therefore:

- Healthy adults of different ages and differing balance control turn differently.
- If turning is found to necessitate both simultaneous and sequential movements (movements particularly impaired in PD), a greater proportion of people with PD than people without PD will demonstrate dysfunctional turning.
- People with long-standing, severe PD will demonstrate more dysfunctional turning than will people early in the disease course, with mild symptoms.

Chapter Three

Turning and its Measurement

3.1. Overview of Chapter

Walking turns are an 'integral component of adaptive locomotor behaviour' (Patla et al, 1999). The focus of this thesis is the evaluation of the dysfunctional turning commonly experienced by people with PD and, in this chapter, I review what is known about how turning is accomplished and the methods and tools used by other researchers. In Chapter Two, turning was identified as an activity associated with freezing and falling in PD. In this chapter, the prevalence of dysfunctional turning is considered further (Section 3.2) and the conclusion reached that turning difficulties are among the most common symptoms of PD. Although both are characteristic of PD, much more is known about difficulty turning over in bed (recumbent turning) than difficulty turning in standing and walking. Research on recumbent turning has focused on reported difficulties and observed abnormalities; the body of research can be criticised for an over-reliance on survey, the restricted samples studied and the use of unsubstantiated concepts of normality. Nieuwboer et al (1998) demonstrated a highly significant correlation ($P < 0.001$) between the abilities of people with PD to turn in standing and roll in lying. Difficulty turning in lying and in standing may not be entirely different phenomena. They may in fact share common features, so the nature of both difficulties turning in lying (Section 3.3) *and* in standing (Section 3.4) is discussed and the ways in which they have been evaluated critically reviewed. Finally, the key issues arising from the literature are summarised and the requirements for a new research tool, suitable for the evaluation of turning in PD, proposed (Section 3.5).

3.2 The Prevalence of Dysfunctional Turning

The prevalence of turning difficulty in samples of people with PD has been widely reported; the results suggest that three out of four people with mild to moderate PD have difficulty turning in bed. In one of the largest surveys, only 'slow walking and dressing' and 'difficulty rising from chairs' were more prevalent complaints than difficulty turning in bed (Mutch et al, 1986): 79% of approximately 200 people questioned (average age 75 years and time since diagnosis seven years) reported problems turning.

Lees et al (1988) studied a similar size sample: 65% of the 220 participants reported difficulty turning in bed and 98% of the entire sample reported sleep disturbance, some of which may have been attributed to difficulty turning. Lakke et al (1980) surveyed 103 ambulant, drug-responsive individuals and 80 (78%) reported problems turning. A similar prevalence was reported by Nieuwboer et al (1998). Of 60 outpatients with PD, average age 64 years (range 20 - 82), time since diagnosis eight years (range 1 - 21), Hoehn and Yahr Grade II (range I - V), 75% had difficulty rolling. The researchers applied the criteria devised by Lakke et al (1980) and achieved a Kappa value of 0.83 when agreement between raters was assessed. Ashburn et al (2001) interviewed 39 people with PD (average age 74 years, time since diagnosis five years, Hoehn and Yahr grade III) and, once again, a similar proportion (31, 79%) described difficulty turning.

Beyond *difficulty* turning, the prevalence of the *inability* to turn has also been reported. Seven of the people interviewed by Ashburn et al (18%) were unable to turn in both directions and a quarter of the 36 outpatients investigated by Steiger et al (1996) were unable to turn over. The sample investigated by Steiger et al had a mean age of 55 years (range 32 - 76), disease duration of 11 years (range 2 - 28) and a median Hoehn and Yahr Grade of III (range I - V). Twenty-one of the 71 PDS branch members surveyed by Mutch et al (1989), i.e. 38%, were usually or always *dependent on another person* for assistance when attempting to turn over.

The prevalence of difficulty turning in standing has been less frequently reported. Of Nieuwboer et al's (1998) 60 outpatients, 52% had difficulty turning in a confined space. Motor Blocks are sudden, short-lasting episodes of breaks in motion as well as inhibitions in executing a movement or switching from one movement pattern to another, often described as 'freezing' (Giladi et al, 1992). From their large survey of 990 people with PD, Giladi et al found that the most common cause of freezing identified was start hesitation (reported by 273 people, 28%). Freezing during turning was more prevalent than the well recognised problem of freezing at doorways (reported by 143 people (14%) and 80 people (8%), respectively). A motor block during turning was taken to mean that the individual got stuck in the middle of a turn because of a transient inability to make the necessary leg movements.

These studies had methodological problems. Several descriptive surveys, reliant on the participants' accounts, were completed, while few researchers *observed* the performance of turning. Nieuwboer et al (1998) did both interview *and* assess their participants: the proportions that reported difficulty rolling and turning were similar to the proportions that demonstrated difficulty. The participants recruited have tended to be in the early stages of PD, i.e. having mild or moderate symptoms and being ambulant and responsive to medication and most have been studied when under the age of 75 and within ten years of diagnosis. More men than women have been studied and clinic samples have been described more often than community samples. Some samples have been of unusually early disease onset (mid 40's to mid 50's). Finally, some researchers (e.g. Steiger et al, 1996 and Lakke et al, 1980) have used unsubstantiated concepts of 'normality' (see Section 3.3).

Dysfunctional turning appears to be a common problem for people with PD. In defining abnormality (and proposing a cause) it is essential to have an idea of what constitutes 'normal' and a tool with which to distinguish abnormalities. These issues are discussed in the following sections, firstly with reference to turning in lying and secondly with reference to turning in standing and walking.

3.3 Recumbent Turning

3.3.1 What constitutes a 'normal' turn?

Little description of how healthy adults turn in lying has been made. Kamsma et al (1994) described recumbent turning as a complex motor task, in which the components need delicate tuning in terms of sequential and simultaneous execution'. They observed that healthy adults created an arch with one arm and leg, around which to rotate their body. Kamsma et al completed a kinesiological assessment of turning over in bed, involving ten healthy young people, ten healthy elderly people and ten people with PD and achieved acceptable agreement between the raters who evaluated the turns demonstrated from video (Kappa 0.72). The time taken to turn by the group with PD was considerably longer (a mean 10.7s $\pm$ 3.8) than the times taken by the other groups (2.6s ($\pm$0.6) and 3.6s ($\pm$0.5), respectively).

The study illustrated the shift from simultaneous to successive action in the group with PD. In attempting to create an arch around which to rotate, they used more points of support than the other groups; it was the failure to form an arch that made their movement fragmented and ineffective, argued the authors.

3.3.2 Difficulties and Abnormalities

The focus of the recumbent turning studies summarised in Section 3.2 was either self-reported difficulty or observed 'abnormality': these will be considered in turn.

3.3.2 a Difficulty Turning and associated Sleep Disturbance

People with PD frequently experience disturbed sleep (Partinen, 1997) and *difficulty* turning in bed is prominent among the possible causes (alongside the disease process, i.e. neurochemical changes and discomfort, depression and drug therapy). Researchers have shown that, compared with healthy controls, people with PD have more difficulty turning so that they change position less frequently and experience more sleep disruption (Laihinen et al, 1987; Weller et al, 1991 and Van Hilten et al, 1993). Laihinen et al (1987) found that people with PD made fewer movements in bed at night than did the controls. Prolonged immobility often fully awoke the people with PD observed. Their sample was small (nine people with PD and 11 controls) and few participants had severe PD (the median Hoehn and Yahr Grade was II). Later, Weller et al (1991) found that people with PD changed position less often than did their spouses. Details about sampling and recruitment and the characteristics of the 24-strong PD group (mean age 71 years) were scant. Van Hilten et al (1993) interviewed 90 people with PD (median disease duration six years) and 71 without, seeking to identify those experiencing sleep initiation and sleep maintenance problems and the associated causes (such as difficulty turning, nycturia, pain and stiffness). Similar proportions of both groups reported sleep-maintenance problems (74% of those with PD and 76% of those without): sleep-maintenance problems associated with difficulty turning were significantly more prominent among the former. Sixteen of the 67 people with PD who found sleep maintenance problematic (24%) attributed the problem to difficulty turning in bed, in comparison with just two of the 54 people without PD who had a sleep maintenance problem (4%). Unfortunately, the authors discussed their findings very briefly.

3.3.2 b Abnormal Recumbent Turning

Whilst many people with PD find turning difficult, if not impossible, others are thought to turn abnormally. However, what constitutes a 'normal' turn remains unclear and findings, such as those of Lakke et al (1980), must be interpreted with caution. Steiger et al (1996) described an 'unusual' method of turning by ten of the 36 outpatients they studied i.e. 28%. Lakke et al (1980) described 'abnormal' rolling in 11 of the 26 people they studied, i.e. 42%, but their rating scale was presented superficially, with notable omissions in the methods. In the former example, 'abnormal' was defined as using the free hand to push or sit up: in the latter, 'abnormal' was defined as pushing with the arm or leg, an absence of armswing and the initiation of movement by knee bending. Normality and abnormality need not be defined: Ashburn et al (2001[a]) successfully described the turning strategies used by 38 independently mobile people with PD, without reference to either. Most of their participants (31, 82%) could turn in both directions; three turning strategies commonly deployed were *multiple hip hitching* (used by 87%), *sitting up* (52%) and *pulling on an external support* (45%). The participants unable to turn both ways had more severe PD than those who could, as rated on the UPDRS, Hoehn and Yahr Scale and SAS, although both groups had been diagnosed similar lengths of time (medians of six years and five years, respectively).

3.3.3 The Measurement of Recumbent Turning

Recumbent turning is a distinct item to be rated on the New York Rating Scale, the McDowell Disability Index, the Self-assessment Disability Scale and the UPDRS. Researchers have devised scales specifically to rate the ability to turn in supine (Lakke et al, 1980 and Steiger et al, 1996). In addition to these rating scales, a number of researchers have deployed more high-technology approaches to evaluate turning in bed, that reveal the quantity of movement rather than the quality. Weller et al (1991), for example, used a participant-operated, purpose-designed rotation sensor and digital data store attached to the sternum. This provided a continuous record of night-time axial rotation, from which it was possible to ascertain, for example, the number of positions adopted, the sum of angular displacements and the time spent attaining the positions.

3.3.4 Causes of Dysfunctional Recumbent Turning

Despite the lack of description of abnormal or dysfunctional turning, several explanations for the underlying cause have been proposed. Disordered axial rotation is thought by some (notably Lakke and colleagues) to arise from lesions in certain non-dopaminergic pathways as the symptom is only weakly related to more distal symptoms and resistant to the beneficial effects of levodopa therapy. Lakke et al (1980) suggested that 'active rotation around the truncal axis is a unique postural motor activity utilising special neuronal mechanisms'. In 1982, having studied 41 people with PD, Lakke et al found turning, rising and walking to constitute a distinct symptom cluster. In 1985, Lakke used three case studies to illustrate his argument that certain axial motor features could be described as 'apraxia':

- Axial functions deteriorate although L-dopa improves other motor features.
- Axial movement remains difficult during hyperkinetic 'on' periods.
- Axial programs remain intact; movement is possible under some conditions.
- People with PD can describe their inadequacies and adopt alternative strategies.
- Physiotherapy does not improve axial motor behaviour.

Lakke dismissed the possibility that difficulty turning in bed was due to akinesia (which responds to L-dopa), rigidity or dementia (not evident in his case studies), night-time L-dopa depletion (as it occurs during the day) or defective postural mechanisms (found to be distinct in his 1982 study). Steiger et al (1996) disagreed with Lakke's apraxia theory and attributed difficulty turning in bed to the 'inability to execute the sequence of axial movements required to achieve the task'. They proposed that the deficits were attributable to movement slowness and disrupted sequencing, with difficulties arising from 'adopting inappropriate turning strategies' for what was once automatic.
Steiger et al compared volunteers with and without difficulty turning (similar in age and age at onset) using the King's College Hospital Rating Scale and found several significant differences between the groups. Those with difficulty turning had been diagnosed longer and had more severe PD (e.g. more impaired balance and gait, more axial rigidity and body bradykinesia) than those without difficulty turning. Axial items were all highly inter-correlated, further evidence, perhaps, that axial and limb movements are controlled by separate systems.

They discussed the possibility that the pathology of PD differentially affects the 'postural' motor column arising from the supplementary motor area (influencing axial and postural muscles) and the higher centres controlling voluntary activity. According to Ashburn et al (2001[a]), people with PD attribute difficulty turning in bed to weakness, pain, stiffness and freezing.

3.4 Turning when Standing and Walking

3.4.1 What is 'normal'?

In contrast with straight forward gait, little is known about turning in standing and during walking, however a number of studies are beginning to illustrate the requirements for performing a walking turn. The studies are discussed below, firstly those describing the transition from straight forward gait to turning and secondly those addressing the control of the head and vision during turning.

3.4.1 a The Transition from Straight-line Gait to Turning

Recently, Patla et al (1991 and 1999), Cao et al (1997 and 1998), Hase and Stein (1999) and Thigpen et al (2000) have published work on the ways in which healthy people turn and clearly highlighted the complexity of moving from walking to turning. As Hase and Stein (1999) stated 'quickly turning the body, while still maintaining balance and some momentum' is 'extremely complex'. Patla et al (1999) described walking turns as 'a challenging task for the locomotor control system.'

Patla et al (1991) described the dynamics of the gait adjustments needed to execute a change in walking direction when visually cued so to do and found that although step width and length could be altered within an ongoing step cycle, direction change could not. They attributed this inability to muscle activity being insufficient to rotate the body and achieve translation along the medio-lateral axis. As such, direction change was planned in the preceding gait step, so as to reduce the acceleration of the Centre of Mass (COM) of the body over the landing foot to zero.

Patla et al measured ground reaction forces, muscle activity and the kinematics of changing direction during gait. Their study involved a small sample of undergraduates and demonstrated that:

- Turning cannot be instigated during an ongoing step as the direction of turning is planned in the preceding step.
- To turn successfully, one must decrease velocity in the sagittal plane, accelerate the COM in the mediolateral plane and modulate the moment around the vertical axis.
- The inability to turn is due to the inability of hip and ankle muscles to generate the necessary forces.

Patla et al (1999) investigated the transition stride (between straightforward gait and turning) observed in 'online steering'. They described the sequencing of the necessary subtasks (reorientation of gaze and of the body and control of the COM in the medio-lateral plane) when steering was planned early, at the start of walking, or late, 1 stride before turning. Participants were cued to turn during 50% of the experimental trials as they walked with markers on the face, chest and toes. Straightforward gait was characterised by minimal deviation of the feet in the medio-lateral plane and minimal displacement of the head and trunk yaw. When turning, control of the COM preceded the other changes, followed by head then body reorientation. Patla et al concluded that the CNS used two mechanisms to steer the COM (i.e. control its trajectory), Foot Placement (FP) and Trunk Roll Motion (TRM). FP (dictated by foot control during swing with or without adjustments via the muscles of the ankle, hip and trunk in stance) dominated when turning was planned early and was effected by cue time and turn magnitude; TRM dominated when turning was cued late.

Cao et al (1997) measured people's success rate when making unexpected 90° turns on a cue, given an Available Response Time (ART) in which to turn of between 375 and 750ms. Their study involved 20 young people and 20 elderly people. For all ARTs, the success rate for completing a turn was lowest in the elderly group; e.g. given 375ms in which to respond, the rate was 6% in the elderly group and 36% in the young group. Cao et al (1998) investigated the extent to which age and sex differences in the ability to turn quickly affected the time needed to arrest momentum on a cue.

The largest single contributor to the difference in the needed response time between the two age groups studied was a prolonged duration early post-cue response in the elderly group. Sex differences were apparent in the elderly group: men demonstrated greater acceleration during the early post-cue response, whereas women demonstrated reduced deceleration during a subsequent response phase. In the young group, no one parameter was *primarily* responsible for the sex difference found. Cao et al attributed their findings to the known age and sex differences in the ability to rapidly develop leg joint torque strengths. They identified significant age and gender differences in the ART needed to make a turn.

Hase and Stein (1999) also studied walking 180° turns. They investigated ten healthy people (five men and five women), aged between 26 and 57 years, performing cued turns, at a preferred pace, in both directions. The cue was a strong, non-noxious, electrical stimulus to the Superficial Peroneal Nerve, near the right ankle. Hase and Stein identified two turning strategies (the 'Spin' Turn and the 'Step' Turn), the use of which was dependent on the laterality of the leading leg (used for braking) when the directional cue to turn was given. They concluded that turning consisted of 'decelerating the forward motion, rotating the body and stepping out in a new direction'. After decelerating, the participant chose a turning strategy and in both strategies the forward leg became the axis for rotation. A (right) turn of each type is described below.

The Spin Turn

This turn type is used when the ipsilateral leg was leading at the time of the cue; the participants 'altered direction by spinning the body around the foot'.

- The cue was given at left heel strike.
- Force came off the left heel and onto the ball of the left foot.
- Force comes quickly off the ball of the left foot and onto the ball of the right foot.
- The right foot was placed towards the midline with external hip rotation. Force remains on the ball of the right foot while the body rotates around the right leg.
- The left foot is placed 'in front of or to the side of' the right foot.
- The right leg steps in the new direction of movement.

The authors used the term 'axial leg' for the limb supporting the body weight during the change in direction. In the spin turn 'the body spins around the ball of one foot, which serves as an axis for the turn'. Keeping the torso behind the axial leg was supposed to 'balance the centrifugal force caused by rotating the body', so this strategy could not be used when the COM had passed the stance foot.

The Step Turn

This turn type is used when the contralateral leg was leading at the time of the cue; participants shifted their weight to the leading leg, externally rotated and then shifted weight on to the other leg and continued turning. The earliest stages of the description are very similar to those of the Spin Turn.

- The cue was given at right heel strike.
- Force came quickly off the right heel and onto the ball of the right foot.
- Force comes quickly off the ball of the right foot and onto the ball of the left foot.

At this point, differences between the types of turn emerge.

- Another (right foot) step is quickly initiated; both feet rotate, facing diagonally to the new direction.
- The left leg steps, landing on the heel, pointing in the new direction.

The authors considered this turn 'easy and stable' because the base of support was wider than the spin turn. Unlike the Spin Turn, 'both feet continue to step, and each can serve as the axis for part of the turn'. The turning strategies could be divided into these 'two common styles' for seven of the ten participants but the other three always used a stepping strategy, a finding for which the authors could offer no explanation. In contrast to Patla et al (1991), Hase and Stein concluded that turning was 'essentially complete within a step cycle' and that, when successful, turning was so smooth that walking continued 'with little or no change in timing'. They proposed that deceleration and the alternative turning strategies were simplifications to negotiate a complex manoeuvre.

3.4.1 b Vision and Head Control during Turning

These studies led researchers to conclude that, during walking turns, head direction was controlled in a predictive fashion (Grasso et al 1996, Imai et al 2001). Grasso et al (1998) and Hollands et al (2000) suggested that anticipatory deviation of the head and gaze when walking reflected the need for a stable frame of reference for the intended action: this 'feed-forward' control appears in childhood (Grasso et al, 1998b). Restricted head movement affects the motion of the trunk during turning (Hollands et al, 2000).

In their 1996 study, Grasso et al described the control of head direction during turning as a 'go where you look' strategy. As their participants negotiated a planned circular trajectory (with and without a blindfold) head direction changes anticipated changes in locomotion direction by approximately 200ms, with the anticipation interval dependent on the curvature of the trajectory. Without a blindfold, head deviation was toward the inner concavity of the trajectory. Similarly, Imai et al (2001) showed that movements of the body, head and eyes maintained the gaze in advance of the head during turning. They measured such movements during straightforward gait and during 90° turns following two marked trajectories, one of 50cm radius completed in two steps and one of 200cm radius completed in five to seven steps. During turning, orientating mechanisms (not operative during straightforward gait) directed the eyes, head and body to tilts of the Gravito-inertial Acceleration Vector: the tilt axes of the head and Gravito-inertial Acceleration Vector aligned during turning. The gaze was stable unless the angular velocity of the turn was high, when the gaze 'jumped' along, leading the trajectory.

Grasso et al (1998) produced further evidence supporting the use of anticipatory orientating synergies when negotiating planned trajectories. In their experimental set up, participants turned along 90° trajectories, both forwards and backwards. The behaviour was the same with the eyes open and shut: the head and eyes deviated to the future direction of trajectory with an anticipation of approximately one second. When walking backwards, the gaze deviated in the opposite direction to that of the planned trajectory. From their findings, Grasso et al concluded that anticipatory deviation of the head and gaze when walking provided a stable frame of reference.

Like Grasso et al, Hollands et al (2000) found that the head turned first when a walking change of direction was attempted. They completed a biomechanical analysis of steering through 30° or 60° turns (when visually cued), with and without head immobilisation and built on Grasso et als' work by considering the contribution of FP to postural adjustment. They observed that the lateral translation of the body's COM was achieved through alternate placement of the contralateral foot prior to the turning step coupled with a hip strategy during the swing phase. In comparison with free walking, steering with the head immobilised in respect to the trunk was associated with earlier trunk yaw and later (and reduced) trunk roll.

Grasso et al's work (1998b) on the development of the anticipatory synergies described above revealed that, like adults, children under eight years of age showed predictive orienting strategies. In young children, however, head rotation occurred later than in adults (i.e. at the point of making a 90° turn, rather than prior to turning). They suggested that this type of anticipatory mechanism probably becomes increasingly important over time.

3.4.1 c Criticism of the Body of Literature

Two major criticisms can be levelled at the body of literature summarised above:

1) The work has methodological limitations, breadth without depth and
2) It is largely inapplicability to people with PD

Methodological Limitations

The published research forms a nebulous body of work, so despite the quantity of research, the evidence established is weak. Whilst many aspects of the performance of turning have been addressed, there is little depth in any aspect because the investigators have used so many different designs and tools, for example:

- Patla et al (1991 and 1999) measured ground reaction force, muscle activity and whole body kinematics.
- Cao et al (1998) focussed on the forward momentum of the abdomen, and
- Hase and Stein (1999) used pressure sensitive insoles, electrogoniometry and EMG.

Among those interested in vision and head control:

- Grasso et al (1998) and Imai et al (2001) analysed 90° turns
- Hollands et al (2000) focussed on 30° and 60° turns
- Grasso et al (1998) recorded head, trunk, hip and foot movement using ELITE.
- Hollands et al (2000) focussed on postural control and the sequencing of segment reorientation, and
- Imai et al (2001) used video-based motion analysis plus video-oculography.

Given that these studies had very different foci, the numerous methods deployed reflect the complexity of turning and the possibility of measuring many of the elements contributing to its performance. As the studies are so disparate, there is, as yet, no consensus about the performance of a walking turn. Unlike straightforward gait, there is no accepted terminology for the constituent elements of turning: the equivalent of 'the gait cycle', with its constituent phases from heel strike to the same point one stride later has not been established. One consistency across the studies is the type of sample studied, though this too is a limitation.

Inapplicability to People with PD

With few exceptions, individual studies have involved very small samples (usually fewer than ten). Hase and Stein (1999) reported on ten people, Grasso et al (1998b) eight, Grasso et al (1998) and Patla et al (1999) six, Grasso et al (1996) and Imai et al (2001) five; Morris et al (2001) reported on just three people. Such small samples perhaps reflect the nature of the studies, which may have been demanding, generated considerable, complex data and been preliminary to larger investigations but nonetheless, the findings must therefore be interpreted cautiously. One of the studies had a considerably larger sample size than the rest: Cao et al (1998) reported on 40 participants. However, this sample was reduced in size when it was divided into groups to allow the comparison of young and elderly people. The literature is dominated by studies of young, healthy volunteers. For example, Imai et al's (2001) participant mean age was 29 years, Patla et al's (1999) was 23.

Furthermore, researchers have largely evaluated turns performed on an external cue (be it visual or sensory). Applying such designs to investigate how people with PD turn might artificially and temporarily enhance the participants' performance. As Yekutiel (1993) highlighted, the performance of an individual with PD can be 'acutely sensitive to context . . . good on stage in the clinic' but unreliable in his or her own environment. The 'poor correspondence between behaviour in real life situations and performance on motor tasks in the laboratory' is an issue that must be addressed when planning research that involves people with PD.

3.4.2 Difficulties and Abnormalities

3.4.2 a Key Publications since this work Began

Three recent papers have addressed some of the issues central to this thesis, including indicators of difficulty turning, how people with PD turn and the standardised testing of the ability to turn: each is critiqued separately below.

Thigpen et al (2000)

Thigpen et al deployed a complicated method to identify and describe the movement characteristics that they considered to be indicators of difficulty turning 180° while walking (in elderly people): people with PD were excluded from the study. The turns that they analysed were performed during the Timed Up and Go Test (Podsiadlo and Richardson, 1991) and defined as 'the beginning and end of the 180° reversal of direction at the turn line on the floor while walking'. Time and steps taken were recorded, as was the dominant movement in the upper and lower limbs and trunk. They video-recorded 20 young people (university staff and students, age range 20 - 30) and 15 elderly people (age range 65 - 87) *without* difficulty turning performing self-paced walking 180° turns. The former turned in a mean 1.4s (± 0.3), taking 1.3 (± 0.4) steps, the latter in a mean 2.1s (± 0.7), taking 2.3 (± 1.4) steps. A group of 15 elderly people who *reported difficulty turning* (age range 69 – 92) turned in a mean 3.2s (± 1.0), taking 4.7 (± 2.1) steps.

The work contributes to the description of 'normal' turning. During turning, the upper limbs were observed predominantly to swing asymmetrically in the young group, be held by the sides in the elderly group without turning difficulty and be held 'raised' in the difficulty turning group. 'Backward trunk lean' was predominant in the young group, while 'vertical alignment' was observed in the two elderly groups. With reference to the lower limbs, 'an early pivot approach' with the body already rotated approaching the line on the floor was predominant in the young group, while a 'mixed strategy' combining 'steps and partial pivots' was observed in the two elderly groups. They considered turn-type to be a 'developmental change' in response to 'subtle changes in balance'.

Thigpen et al distinguished four factors that indicated difficulty turning: a turn-type characterised by an 'absence of pivot', five or more steps or weight-shifts, a turn time of three seconds or longer and staggering. These were the four characteristics exclusive to the group who reported difficulty turning and 'appeared to reflect impaired stability during turning'. The authors proposed that self-report of difficulty turning while walking may serve as an indicator of a loss of overall mobility that might otherwise escape notice. Reliability of the video-based analysis was based on the percentage agreement between two physical therapists: a Kappa value of 0.90 was calculated for time, a value of 0.67 for steps, 0.78 for turn type and 0.71 for 'staggering' when turning.

The study can be criticised on several fronts. Primarily, the indicators of difficulty were defined in the same group of elderly people that was then compared with the other groups. Reliability testing was repeated on the same set of videos until an acceptable agreement reached. Continuous data for time and steps was categorised to assess reliability although it was used in its continuous form in the analysis.

Morris et al (2001)

Morris et al considered the ability to turn 'an integral part of functional locomotion', with stability maintained at the cost of efficiency. They conducted a small experimental study and reported the spatio-temporal and kinematic differences found between the online turns of one 78-year-old individual with PD (Hoehn and Yahr Grade III), one 76-year-old control and one 24-year-old control. The subjects walked on a walkway and Morris et al recorded preferred speed, unidirectional turns, on a force plate, towards visual targets at 30°, 60°, 90° & 120°. For each participant, they analysed one trial to each target, considered 'representative' of the six trials completed by each subject, from 'two steps in to two steps out of the corner'. The gait of the person with PD studied was slower (0.99m/s), of shorter stride length (1.06m), wider stride width (a mean inter-heel distance in lateral plane of 0.13m) and higher cadence (125 steps per minute) than the other participants; differences in turning were also identified. The participant with PD took more steps than did the controls in every turn, the number of steps increasing as the turn magnitude increased, from which Morris et al concluded that the increase in step number reflected increasing difficulty turning.

In the first turning step, the lateral toe trajectories of the controls increased from the 30° to the 60° turns; they then decreased in the 90° and 120° turns, accompanied by additional steps, which Morris et al assumed enhanced stability. As such, they suggested that the 60° turn was the least stable of the four: without extra steps, more trunk control would have been needed during long swing phase of the second step. Despite the greater stride width of the participant with PD than the controls during straight gait, his double support base during the 'critical turn phase' was reduced in width in comparison with those adopted by the controls. From differences in the trajectories of the shoulder and COM during turning, they concluded that the participant with PD was keeping his COM within the limit of stability, another compensation for an impaired ability to turn. His first turning step was within the area covered by forehead, shoulder and pelvis markers.

The paper lacks detail about participant recruitment and baseline compatibility. The research design is open to question: what turning on a force plate reveals about normal foot placement during turning is debatable. The study size must be kept in mind when interpreting the findings.

Simpson et al (2002)

Simpson et al described their TURN180 as a simple measure of dynamic postural stability for testing frail elderly people. In designing the test, they chose a 180° turn, as it was 'an essential manoeuvre when preparing to sit down' and to count steps, rather than time the test, as timing, they argued, would preclude giving warnings or encouragement and 'pauses might be difficult to interpret'. Very explicit instructions were given to the individuals being tested. They stood surrounded by tables, chairs or other stable handholds, then, on the word 'Now', stepped around (180°) to face the observer, keeping their hands by their sides: 'Now' was used rather than 'Go' as the latter may have implied a need for speed. Participants were asked to complete a second trial, turning in the opposite direction. The sample described consisted of 142 elderly inpatients, mean age 81 years (± 6), who had been admitted to acute medical wards, were able to walk 3m without the help of another person and able to co-operate with testing. Most participants (81%) took the same number of steps plus or minus one when turning in each direction.

The mean number of steps taken in the first direction was 6.4 (± 3.9) and in the second trial (in the opposite direction) 6.2 (± 3.4). No consistent learning effect was detected. There was a tendency for the difference between the counts in each direction to be related to the mean of the two counts. When the mean ratio of the two step counts was calculated, it was apparent that most counts in one direction would be within 50% more or less of the count in the opposite direction. The mean step count during the TURN180 correlated weakly with the number of falls recalled over six months ($r = 0.4$, $P = 0.001$) and perceived steadiness, rated by participants on a four-point scale ($r = 0.4$, $P = 0.001$).

Simpson et al provided little information about the sample, e.g. reasons for admission to hospital. The reasoning behind some analyses was not clear; for example, they claimed that their study demonstrated that two out of three elderly people turn clockwise when given the choice. The step count used was based on attempts to shift body weight, successful or not, with alternate feet. How reliably an observer can judge an unsuccessful attempt to achieve a movement is questionable; reliability had not been tested at the time of publication. The reason why only steps with alternate feet were counted is not expanded upon.

The authors appeared optimistic that the test could replace 'longer, more complex tests of dynamic postural stability', having only demonstrated a correlation between perceived steadiness and the number of steps taken to turn round in a circle of chairs. In discussing the interpretation of scores, the authors made two claims based on 'clinical experience' although no data connected to the claims were presented anywhere in the paper. Firstly they suggested that 'patients with PD may complete the task in 18 to 20 steps' and secondly they that 'patients with painful knees may complete the task in six steps'.

Taken as a whole, a similar criticism can be levelled at the body of work discussed above as was levelled at the body of literature discussed in Section 3.4.1. Turns of different magnitudes have been studied in different ways, providing a breadth of knowledge but little depth. Thigpen et al conducted video analysis of walking 180° turns; Morris et al used reflective VICON markers to take measurements during 30° to 120° turns and Simpson et al counted steps during a 180° turn 'on-the-spot'.

3.4.2 b Dysfunctional Turning associated with PD

In PD, freezing, falling and loss of balance are frequently experienced during turning, often associated with turning too quickly or in a confined space, distraction and the fear of falling (Ashburn et al, 2001) but little is known about how people with PD turn. Ashburn et al described the ways in which 41 people with PD turned 180^{o} when making a drink in their own kitchens:

- The median number of steps taken was five but varied greatly (to a maximum of 17).
- 89% of participants used the space available (rather than avoiding open spaces).
- 83% demonstrated reduced heel-strike on turning.
- 32% appeared unstable.
- 17% held on to some form of fixed, external support as they turned.

People with mild PD took more steps than did those with severe PD ($P<0.001$) and a greater proportion used support when turning ($P=0.041$). Although repeat-fallers and non-repeat fallers turned in similar ways when making a drink, the former adopted a significantly narrower base (a median 5.5cm between the heels) than did the latter (median 8cm) when asked to turn *on-the-spot*. Similarly, Charlett et al (1998) showed that, in comparison with controls, people with severe PD had a narrower (mid-swing) foot separation and those with mild PD a wider separation. They proposed that increased base breadth might stabilise gait but add to the difficulty of turning. Interestingly, the key determinants of foot separation in the control group were gender and height, whereas those in the PD group were rigidity (which decreased separation) and postural flexion (which increased separation). Charlett et al suggested that the risk of falling increased when the effects of rigidity overcame a compensatory increase in base breadth.

A number of theories have been proposed to explain why turning is difficult in PD. Giladi et al (1992) proposed that abnormal retrieval or use of motor programmes (i.e. switching between programmes) led to freezing. As people with PD often walk well once the motor block is overcome, Giladi et al argued that the cause of freezing could not be 'leg stiffness or bradykinesia'. Blocks on turning, they proposed, were caused by 'abnormal switching from one motor program to another'. The study was a retrospective survey of the Parkinsonism database at Columbia University, New York.

The database contained three fields on the form of motor block if any and the presence of non-gait motor blocks and motor blocks when 'on'. Steiger (1994) attributed difficulty to degeneration of the brainstem nuclei involved in axial motor control and within the non-dopaminergic pathways arising therein. Later (1996), Steiger et al proposed that different pathways controlled different movements, i.e. while corticospinal pathways controlled distal (limb) movements, axial movements where controlled by reticulo- and vestibulospinal pathways. More recently still, Nieuwboer et al (1998) proposed that symptoms including gait initiation difficulty, falling and turning difficulty constituted a distinct cluster.

3.4.3 Measuring Turning in Standing or Walking

This section covers observational evaluations of turning in standing and walking. Firstly, PD-specific measures of impairment and disability that require the assessor to consider turning are described, then assessment batteries that include an observation of turning are addressed as are evaluations of turning as a single activity, not part of a battery. Finally, observational measures of turning in PD are discussed. Wherever possible, measurement procedures and the reliability and validity of the tools are considered.

3.4.3 a PD-specific Measures

A number of authors have published scales in which turning is evaluated from observation. Results of a search for published methods of evaluating turning are presented below. CINAHL (R), EMBASE (R), MEDLINE (R) + and the CSP Outcome Measure Database were searched for the key words: Outcome Measures, Turning, Parkinson's Disease, Physiotherapy and Rotation. The PD-specific scales described below in chronological order of publication mention turning as an aspect of either gait or balance. Although the Unified Parkinson's Disease Rating Scale (UPDRS, Lang and Fahn, 1989) has been described as 'probably the only scale to use in large research studies' (Wade, 1996), it, like many measures used to evaluate disability in PD, makes no mention of turning.

The **Northwestern University Disability Scale** (Canter et al, 1961) is a valid and reliable scale with five sections, each (*Walking, Dressing, Hygiene, Eating and Feeding* and *Speech*) scored from zero (the worst score) to ten (the best). *Walking* is divided into three bands, *Never, Sometimes* and *Always walks alone*; turning is mentioned under the latter.

Northwestern University Disability Scale: Always Walks Alone

7	Extremely abnormal gait: slow, shuffling, posture grossly affected, may be propulsion
8	Poor, slow gait: posture mildly affected, mild propulsion possible, **turning difficult**
9	Gait mildly abnormal; normal posture, **turning difficult**
10	Normal

After studying 800 parkinsonian outpatients from 1949 to 1964, **Hoehn and Yahr** (1967) produced 'an arbitrary scale, based on the level of clinical disability', which allowed for 'reproducible assessments by independent examiners of the general functional level of the patient'. This widely used five-stage scale mixes pathology, impairment, disability and handicap; Wade (1996) argued that it 'should no longer be used' as its reliability was untested and it was 'of historical interest only'. Turning is mentioned under Grade III.

Hoehn and Yahr Grade III

First sign of impaired righting reflexes. This is evident by **unsteadiness as the patient turns** or is demonstrated when he is pushed from standing equilibrium with feet together and eyes closed. Functionally somewhat restricted. Mild to moderate disability.

The **Webster Rating Scale** (Webster, 1968) has been widely used although its reliability is untested. Ten items are scored from zero (the best score) to three (the worst). Turning is mentioned under 'Gait'. This is the only published scale to describe deterioration in the ability to turn.

Webster Rating Scale: Gait

0	Steps out well. **Turns about effortlessly**
1	Gait shortened. Beginning to strike one heel. **Turn around time slowing**. Requires several steps
2	Stride moderately shortened. Both heels beginning to strike floor forcefully
3	Onset of shuffling gait. Occasional stuttering-type or blocking gait. Walks on toes – **turns around very slowly**

The widely used **Columbian Rating Scale** (Yahr et al, 1969; Lang and Fahn, 1989) focuses on impairment. The *Functional Performance* section is scored from 0 (the best score) to 28 (the worst): it comprises seven items. The *Tremor, Rigidity* and *Bradykinesia* sections are scored from zero (the best score) to 20 (the worst): each comprises five items. Turning is mentioned under 'Gait Disturbance' in the *Bradykinesia* section. The rater is instructed to evaluate the patient 'performing as naturally as possible without coaxing or special encouragement'. Yahr et al claimed that the 'specially designed scored examination' was 'carefully defined to assure maximum agreement among observers'. Neither reliability nor validity data were published.

Columbian Rating Scale: Gait Disturbance

0	Freely ambulatory, good stepping, **turns regularly**
1	Walks slowly, may shuffle with short steps but no festination or propulsion
2	Walks with great difficulty, great festination, short steps, freezing and pulsion but requires little or no assistance
3	Severe disturbance of gait requiring frequent assistance
4	Cannot walk at all even with help

Lieberman's Index (Lieberman, 1974) is a five-item index. *Rigidity, Tremor* and *Bradykinesia* are scored from zero (the best score) to four (the worst). *Gait Qualitatively Assessed* and *Gait Quantitatively Assessed* are scored on a six-point scale: turning is mentioned under *Gait Qualitatively Assessed.*

Lieberman's Index: Gait Qualitatively Assessed

0	Normal, good stepping, **turns readily**
1	Minimum impairment; slow, may shuffle with short steps but no festination
2	Moderate impairment; has difficulty, short steps, freezing and festination; no assistance required
3	Marked impairment; has difficulty, frequent freezing and festination; requires assistance
4	Severe impairment; great difficulty, always needing assistance
5	Unable to walk even with assistance

3.4.3 b Assessment Batteries including Turning

Turning in standing and during walking feature in several test batteries (e.g. Tinetti et al, 1986; Berg et al, 1992). These measures were not developed specifically for use with people exhibiting Parkinsonism: so far, Ashburn and Stack (1999) have devised the only scheme for describing the ways in which people with PD perform walking turns.

Tinetti et al (1986) developed the Performance-orientated Mobility Evaluation (POME) because they considered disease-orientated assessments and gait analysis too limited *in isolation*. They combined and expanded both approaches so that the performance of challenging manoeuvres could be observed and the contributing characteristics evaluated. The POME consists of two sub-scales, Balance and Gait: *Turning 360° in Standing* is on the former, *Turning while Walking* on the latter.

Turning 360° in Standing is rated as Normal (no grabbing, staggering or holding while stepping continuously), Adaptive (discontinuous steps with one foot on the floor before the other is lifted) or Abnormal (unsteadiness or holding). *Turning while Walking* is rated as Normal (no staggering, turn continuous with walking and stepping continuously) or Abnormal (staggers, stops before turning or discontinuity).

During development, the instrument was tested on 15 ambulatory residents of a long-term care facility. The percentage agreements between a physician, a medical student and a nurse were high (total scores never differed by more than 10%). Later, Nieuwboer et al (1998) achieved a kappa coefficient of 0.77 when two physiotherapists assessed 30 outpatients turning while walking. Using their scales, Tinetti et al found significant differences between 25 elderly recurrent fallers and 54 elderly non-recurrent fallers with regard to both turning in standing ($P<0.001$) and turning while walking ($P<0.005$). Later, Meldrum and Finn (1993) achieved similar results when they compared 40 elderly fallers with 40 non-fallers: abnormal turning balance and turning while walking were demonstrated by significantly greater proportions of the former (80% and 65%, respectively) than the latter (38% and 33%).

The 14-item Berg Balance Scale (Berg et al, 1992) was developed by researchers attempting to devise a comprehensive, short, simple, safe, valid and reliable measure of balance with the focus on the assessment of performance. Berg et al carried out a comprehensive three-phase validity study. A high degree of both inter- and intra-rater agreement has been established (ICC 0.98 and 0.99, respectively). *Turning to Look Behind* and *Turning 360°* constitute two of the items, each scored from zero (the worst score) to four (the best). Before *Turning to Look Behind* (both left and right), the subject is instructed to 'turn to look directly behind you' and the rater may point out an object towards which the subject should look. Before *Turning 360°*, the subject is instructed to 'turn completely in a full circle, pause, then turn a full circle in the other direction'.

3.4.3 c Evaluations of Turning as a Single Activity

Other researchers have evaluated turning as a single activity, not part of a battery, though they have been very limited in the aspects of performance recorded. The time and number of steps taken to turn are by far the most common variables considered. Imms and Edholm (1981) measured turning in a sample of 71 elderly people. They recorded 180° turns on a walkway, measuring the time taken from passing a beam, turning around and passing back through the beam. The mean turn time was 5.5s (± 2.7). Subgroups of the sample (categorised by mobility) turned in different times (see **Table 3.1**): those with unlimited outdoor mobility turned significantly faster than did those in the other groups.

Table 3.1. Walking 180° Turn Times of Groups with Differing Mobility (from Imms and Edholm, 1981).

	Housebound	Limited Outdoor Activity	Unlimited Outdoor Activity
Time	7.6s (± 2.9)	6.7s (± 3.1)	4s (± 1.3)

Eighteen participants used walking aids during the test: the turn times were similar in the groups using and not using aids (6.3s (± 2.2) v 5.3s (± 2.9)), prompting the researchers to conclude that 'the ability to turn around is not specifically affected'. Likewise, the turn times were similar in the group of 33 non-fallers and 37 individuals who had fallen in the previous year (4.8s (± 2.3) v 6.1s (± 3.0)). Imms and Edholm also assessed the subjects completing an obstacle course that necessitated a number of turns. The 'faults' rated included the following: 'turning not continuous with walking', 'a rail or stick used to assist turning' and, when about to sit down, 'turn not initiated during walking'.

Lipsitz et al (1991) studied 126 ambulatory nursing home residents, including 70 recurrent fallers (who had fallen at least twice within six months) in an attempt to identify modifiable conditions characteristic of recurrent fallers. They counted the number of steps taken to turn 360° in standing and timed the manoeuvre.

Recurrent fallers and the 56 non-recurrent fallers differed significantly ($P<0.001$) on both measures: fallers turned in 13.7 (± 8.3) seconds, taking 17 (± 8) steps whilst non-fallers took 8.2 (± 4.5) seconds and 11 (±4) steps. Individuals who took more than 12 steps or 9 seconds were likely to be fallers. Multivariate analysis revealed the following model for characterising recurrent fallers: (1) use of antidepressants, (2) abnormal joint position sense, (3) more than 12 steps to turn 360° and (4) impaired rising. The model correctly predicted 73% of the fallers and 83% of the non-fallers.

In 1996, Schenkman et al evaluated the 360° turns demonstrated by 57 healthy subjects in three age groups (see **Table 3.2**), taking the average of one trial to each side (recording time with a stopwatch). The number of subjects in each group is not stated in the paper.

Table 3.2. The Number of Steps and Time Taken to Turn 360°
(from Schenkman et al, 1996)

360° Turn	Age 20-40	Age 60-74	Age 75 and Older
Steps (n)	5.2 ± 0.9	6.3 ± 1.3	7.9 ± 2.0
Time (s)	3.2 ± 0.5	3.9 ± 0.9	4.4 ± 13.9

In 1997, Schenkman et al published test-retest reliability for the 360° turn in standing, based on 14 people with PD (mean age 74.5 (± 5.7), Hoehn and Yahr stages II and III). The mean number of steps taken was 9.5 (± 2.9, range 6 - 19) and the mean time taken was 6s (± 2.5, range 4 - 16). The ICC for steps taken was 0.77, that for time was 0.8. The sample was small, the end-point of turning pinpointed, reliability enhanced by multiple trials, assessors trained and rigorous inclusion criteria applied.

The test-retest reliability of a timed 360° turn has been demonstrated by Suteerawattananon and Protas (2000). Eleven people with PD (mean age 75.4 (± 7.3), Grades II-III) completed timed turns 'as fast as possible' on the instruction 'ready; go' and repeated the test one day later (see **Table 3.3**). Reliability was excellent (ICC 0.95) and no practice effect was detected.

Table 3.3. 360⁰ Turn Test-retest Reliability (Suteerawattananon and Protas, 2000)

360⁰ Turn Time (s)	Day 1	Day 2
Mean (SD)	14.3 (15.9)	12.4 (12.8)
95% CI	3.7 – 25.0	3.8 - 21

3.4.3 d Observational Measures of Turning in PD

In research carried out prior to this thesis (Ashburn and Stack, 1999), we outlined the development and use of a system for characterising the ways in which people with PD turn 180⁰ during walking. The categories defined describe six turn types according to the *movements observed* rather than the assumed normality or safety of a turn: data is nominal (**Table 3.4**). In developing the tool, the researchers and two experienced clinical physiotherapists reviewed 30 video-recordings of outpatients with PD turning during walking. Ten physiotherapists used the definitions to rate (from video) 12 people with and without PD turning during walking. Agreement varied from 40% in one video to 90 or 100% in five. Forty-eight people with PD were assessed in a gait laboratory using the categories. Trends in the unpublished data suggested that certain subgroups of people with PD turned differently to others and that people who demonstrated different turn types also demonstrated different mobility and balance characteristics.

Table 3.4. Turn Type Definitions (Ashburn et al, 1999)

Festinating	Multiple small, quick, shuffling steps.
Forwards	Consistently moving forwards (in a U-shape or on the spot).
Backwards	On completion of turning, taking a full step backwards before moving forward in the required direction.
Twisting	Pivoting on one foot or both feet.
Wheeling	Taking a series of steps in an arc, around a central point (like the spokes of a wheel).
Sideways	Whilst turning, taking a sideways or backwards step with one foot.

More recently, we developed a way of video-recording people with PD turning functionally as they moved about their own kitchens, making a cup of tea (Stack et al, 2001). Recording in the home environment presented a number of technical challenges but the movements that were captured were more natural than those demonstrated in the luxury of the purpose-built research laboratory. Two researchers rated the video data (see Section 3.1.3). The inter-rater reliability (percentage agreement and Kappa coefficient *k*) for each variable is shown in **Table 3.5**.

Table 3.5. Inter-rater Reliability of Turning Measured by Stack et al (2001).

Turning Steps (n)	Mean difference 0.06 (± 0.65)	
Use of Support	98%	$k = 0.91$
Use of Space	95%	$k = 0.87$
Decreased Heel Strike	93%	$k = 0.73$
Instability	90%	$k = 0.76$
Turn Type	56%	$k = 0.46$

Turn Type proved to have unacceptable inter-rater reliability when assessed in this way, perhaps because the definitions used were designed for a walking 180° turn under test conditions in a laboratory (under which they have proved reliable). Morris et al (1996) highlighted the need for reliable, valid measures to be used in evaluating movement dysfunction in PD even when fluctuations emerge as the disease progresses. Furthermore, Thigpen et al (2000) concluded that 'a functional assessment that accurately measures difficulty turning would be a useful clinical tool for the early recognition of those individuals at risk of falling'. Having reviewed the many approaches to the measurement of turning discussed above, there is no existing tool or procedure that appears suitable for the thorough evaluation of dysfunctional turning in PD.

3.5 Requirements for a New Research Tool

No existing tool or procedure would satisfactorily generate data allowing the hypotheses proposed in Chapter Two to be tested. Clearly, yet another approach is needed, which is unfortunate as the data collected will not be directly comparable with that of other researchers. The research that has been conducted so far does highlight a number of issues that need to be borne in mind when developing new tools and procedures.

Groups of people (e.g. of different ages, history of falls, pathology) take different numbers of steps when turning but beyond step count and time taken there remains a gap is in the description of *how* people turn. There remains considerable scope for the discussion of what exactly constitutes a turning step. Describing differences in step count and time without collecting additional explanatory information means that little is known about *why* people turn as they do. Acceptable reliability when rating these variables from video has been widely reported. Researchers have not fully discussed the effect speed has on turning; differences in supposedly pathological populations may be attributable to low speed turning rather than primary deficits.

Orientating mechanisms unnecessary during straightforward gait operate during turning. Simultaneous demands are placed on the CNS to control movements from the eyes to the feet while maintaining momentum and balance. In evaluating turning, a judgement about postural stability (CNS success) would be essential. Stability during walking turns is controlled by the management of the COM through controlled deceleration and rotation, dependent on foot placement. In turning from a standing start, the COM would be manoeuvred throughout a potentially unstable activity and the dominant controlling mechanism may be foot placement. There is a need to elucidate the pattern of foot placement used by healthy adults and the explanatory determinants

During walking turns, a choice is made with regard to the type of turn attempted, one determinant being leg position when the need to turn arises, another being the ability to control balance. If, however, a standing-start turn is evaluated, the participants have a free choice of movement-initiating first step, not constrained by lower limb position. As high level planning is involved in turning, people with planning deficits (including people with PD) are likely to find turning difficult.

The planning requirements for turning from a standing start will *differ* to those of walking turns but will not be necessarily any the less. In a standing-start turn, the planning element can be considered as distinct from the need to bring walking momentum under control.

When the available motion between the head and trunk is restricted, the ability to turn is impeded and compensatory alterations in trunk motion become apparent. It is not known which features of a typical parkinsonian turn may be appropriate compensations and which reflect underlying, potentially modifiable impairments. Modification of foot placement may become increasingly important as the potential for compensation elsewhere diminishes.

3.5.1 The Proposed Tool

Unfortunately, difficulty turning is a symptom reported by the vast majority of people with PD surveyed to date but turning is an *essential* component of useful locomotion. As Patla et al (1992) stressed, any comprehensive evaluation of postural stability should include 'specific postures and movements which are part of the normal repertoire and challenge the balance control system': turns from a standing-start certainly fit this description. The steps taken to design and develop a new tool for evaluating standing-start turns are detailed in Chapter Four.

A standing-start turn is functional. How representative turns demonstrated *on a cue, to a target, on a force plate* can be is questionable, yet such externally cued turns have been studied very extensively. Studies have shown differences in the performance of turning when the stimulus to turn was given at different points in the experimental trial.

Analysis of the transition from straight forward gait to turning has been the dominant method deployed; the alternative approach – analysing the transition *from* turning *to* gait - has not been studied so extensively. A standing-start turn allows the individual free choices as to the direction of turn and the movement-initiating lower limb.

Video-recording a standing-start turn allows repeated observation by the same researcher and others. Furthermore, a video camera is a highly portable, unobtrusive piece of equipment, allowing the researcher to travel to study participants rather than vice versa. Nieuwboer et al (1998) found considerable discrepancy between the proportion of people with PD reporting certain motor problems and the proportion demonstrating them when tested in a laboratory. For example, gait initiation problems were reported by 29 people (48% of their sample) but only demonstrated by 6 (10%); freezing at doorways was reported by 14 people (23%) but not demonstrated by one of them.

Thigpen et al (2000) ruled out the use of two video cameras to capture walking turns on the grounds of the impractical amount of space required ($54m^2$) and opted for a single sagittal-view camera. A standing-start turn could be recorded from a position behind the participant, so that both feet were clearly visible prior to turning.

To minimise the possibility of the rating being coloured by The Halo Phenomenon, the video record reviewed would need to consist only of the participant performing the standing-start turn. The Halo Phenomenon was described by Thorndike in 1920: 'The judge seems intent on reporting his final opinion of the strength, weakness, merit or demerit of the personality as a whole, rather than on giving as discriminating a rating as possible for each separate characteristic'.

It was the intention when using the new video-based tool:

1) Not only to record step count and time but also to collect other explanatory data allowing inferences about step count and time to be made.
2) To evaluate postural stability, perhaps the overriding concern of the individual turning.
3) To rate only one item per video observation, as advised by Thigpen et al (2000).
4) To base a comprehensive description of turning on a sample that included young and old men and women, as age and sex differences in strength are partial determinants of the performance of a fast turn.

Chapter Four

The Design and Development of the Standing Start 180° Turn Test (the SS-180)

4.1. Overview of Chapter

The literature review outlined in the previous chapter failed to identify a suitable tool with which to address the hypotheses raised in Section 2.4. The Standing-start 180° Turn Test (SS-180) was created in order to address this omission. The intention was to produce a measure that could be used beyond the laboratory and generate a succinct evaluation of an ecologically valid turn. In Section 4.2, each stage in the design of the SS-180 is reported and discussed. In Section 4.3, the steps taken so far to establish the validity and reliability of the new tool are addressed and the chapter concludes with a discussion of strengths and weaknesses of the SS-180 (Section 4.4).

4.2 Designing the SS-180

4.2.1 Aim

In designing the video-based SS-180, the aim was to overcome some limitations of the existing outcome measures that have been used to evaluate turning. Among the limitations:

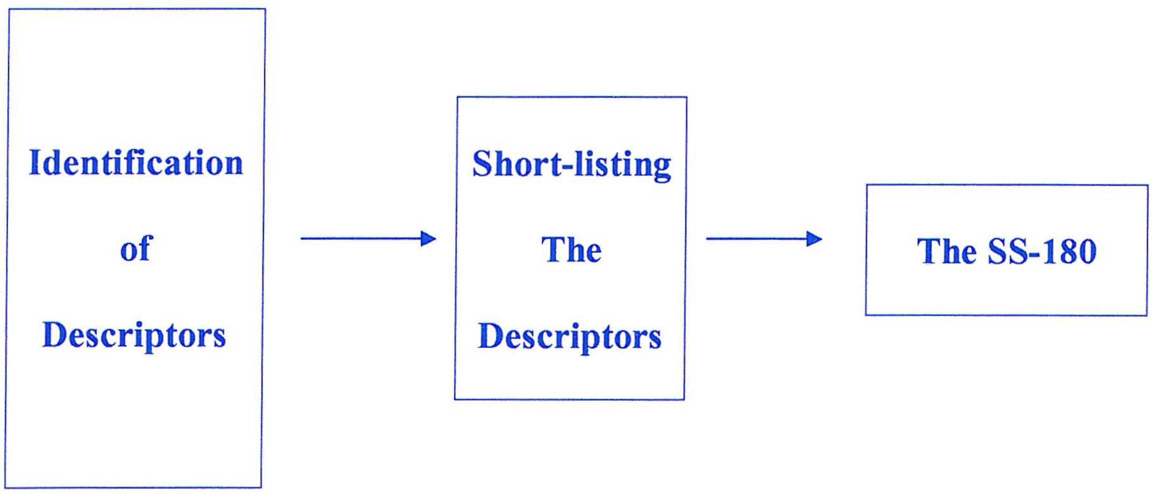
- Turning has been assessed as an aspect of balance, gait or bradykinesia rather than in its own right.
- The terminology used in the PD-specific scales was identified as being vague.
- Half the scales used to describe turning in supine utilised the concept of 'normality' without having established adequately what constitutes 'normal'.
- Most of the specific measures were not designed for use with people with PD and do not take into account all the pertinent aspects of PD. As such, their validity can be questioned, as each measure is limited in its focus.
- Few measures have been designed for the assessment of walking turns; most have been designed for the evaluation of turning in standing, which is arguably less functional.

A new measure was needed that a) focused on the ability of an individual with PD to perform a functional turn, b) was not based on an unsubstantiated concept of normality, c) took into account all pertinent aspects of the activity and d) was worded unambiguously.

4.2.2 Methods

The SS-180 was designed in three reductive stages.

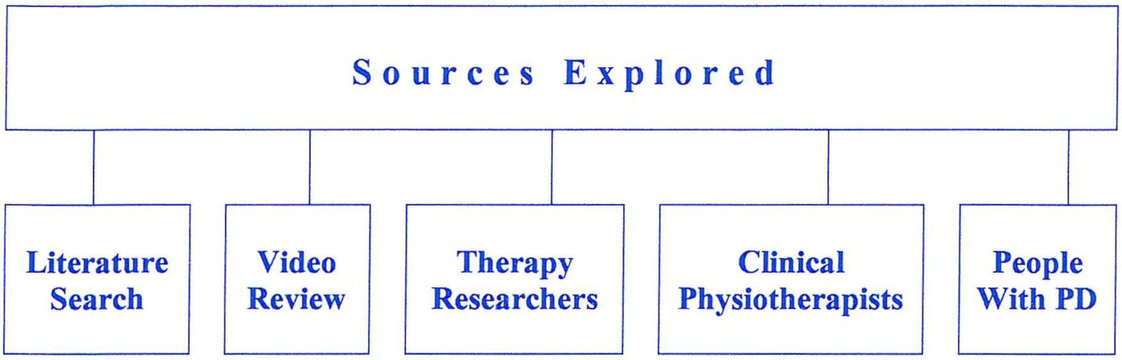
Stage 1. Potential descriptors of turning were identified and pooled.
Stage 2. The pool was reduced to a shortlist of important, measurable descriptors.
Stage 3. The new measure was designed from the shortlisted descriptors.



4.2.2 a Identifying and Pooling Descriptors of Turning

The objective of this phase was to identify from a range of sources potential descriptors of turning that could form items on a new outcome measure (see **Figure 4.1**). A descriptor was defined as any terminology that has been used to describe **a turn** or **a component of turning** or **the ability to turn**. Potential descriptors were extracted from the five sources explored and a list (or pool) compiled.

Figure 4.1. Sources from which were Identified Potential Descriptors of Turning



Source 1: The Literature Search

Objective: To identify published descriptors of turning.

A broad search was undertaken because, at the time of searching, very few specific measures of turning existed. The literature was searched both for outcome measures for turning and, more generally, for measures used in PD that simply *mentioned* turning. The terms and databases used in the search were outlined in Section 3.4.

Source 2: The Researcher's Video Analysis

Objective: to generate further descriptors of turning based on the observation (from video) of people turning under controlled conditions, i.e. under conditions similar to those for which the SS-180 is intended for use.

An existing set of video-records showing 75 people with and without PD demonstrating walking 180° turns during the 'Get Up and Go Test' were utilised. The data had been collected by the researcher during an earlier laboratory-based study (Ashburn et al, 1998) in which a blinded assessor used Stack and Ashburns' (1999) turn-type descriptions (see Section 3.4.3) to rate the turns demonstrated.

Twelve Turn Types and *combinations* of Turn Types had been identified. These were:

1) Festinant
2) Forwards
3) Sideways
4) Twisting
5) Wheeling
6) Festinant and Forwards
7) Festinant and Wheeling
8) Forwards and Sideways
9) Forwards and Twisting
10) Forwards and Wheeling
11) Sideways and Twisting
12) Sideways and Wheeling

The video-record of a man and a woman with and without PD demonstrating each of the 12 turns was selected and reviewed repeatedly at normal speed and in slow motion, while detailed observations were made from which descriptors were extracted. A maximum of 48 video-records would have been reviewed (if a man and woman with and without PD had demonstrated each of the 12 turns).

Source 3: Therapy Research Group

Objective: to generate further descriptors of turning based on the observation (from video) of people turning under non-experimental conditions, i.e. functionally in their own homes, incorporating the opinions of several therapy researchers.

During an ongoing study (Ashburn et al, 2001), people with and without PD were being recorded on video as they made a drink in their own kitchens, during the course of which they spontaneously demonstrated functional 180° turns. A group of six researchers from the University of Southampton, an Occupational Therapist and Physiotherapists experienced in movement analysis, reviewed several of the records and reached a consensus as to which components of turning could be assessed from a video recorded in the home. The components upon which they agreed were added to the list of potential descriptors.

Source 4: Physiotherapists

Objective: to generate descriptors of turning from the perspective of practising clinicians, highlighting the factors that they might consider important when assessing a patient.
The four physiotherapists working on a ward for elderly in-patients at Southampton General Hospital were recruited and asked:

'If a patient with PD, complaining of problems turning round, was referred to you, what might you concentrate on or look out for as you watched them turn?' They were given time to list their responses, after which they were shown a video of twelve people with and without PD performing walking 180° turns in a laboratory. They were then asked, 'Having now seen some people with PD turning, is there anything else you would add to your list – what were you concentrating on or looking out for as you watched the video?' The researcher summarised the content of the therapists' written responses and extracted potential descriptors of turning.

Source 5: People with PD

Having sought input from a range of professionals, the perspectives of people with PD were also explored. Objective: to generate further descriptors of turning incorporating the perspectives of people who had found turning difficult.

Descriptors were identified from two sources. The first was from my earlier work (Stack and Ashburn, 1999), in which the accounts given by independently mobile, community-dwelling people with PD describing previous fall-events were presented. Secondly, in an ongoing study (Ashburn et al, 2001), people with PD had been asked: Do you have difficulty turning and have you modified the way in which you turn? I transcribed the first ten interviewees' responses. A colleague summarised the content of the transcripts. Potential descriptors of turning were identified from the summary.

4.2.2 b Compiling of a Shortlist of Descriptors

Objective: to extract from the descriptor pool a shortlist of those descriptors that were considered both *important* and *measurable*.

It was essential to reduce the pool to a more manageable size before the many descriptors identified from the five sources could be used to construct a new measure of turning. A list of the descriptors was compiled.

Six therapy researchers were asked individually to vote for the 25 descriptors that they considered addressed the most important aspects of turning and the 25 that they considered could best be assessed from video. A descriptor was only short-listed if it met both the following criteria when the votes for the pooled descriptors were counted:

1. Considered important by at least half of the researchers.
2. Considered measurable from video by the majority of the researchers who voted.

4.2.2 c Designing the SS-180 from the Shortlist

The short-listed descriptors were considered one-by-one; those that received the most votes were considered first. Two decisions were made about each descriptor:

1. Should it form a *distinct item* on the new measure or (if significant overlap was apparent) should it be *combined* with another descriptor?
2. Could reliability and concurrent criterion validity be tested?

4.2.3 Results and Discussion

4.2.3 a Descriptors Identified

From the five sources, a total of 70 descriptors of turning were identified and pooled.

<u>From the Literature Search</u>

The search did not identify an existing measure suitable for development but did support the supposition that professionals involved in the assessment of people with PD would be familiar with evaluating turning, as several of the tools identified *mentioned* turning. Having searched the literature for published descriptors of turning, 29 descriptors were extracted from 15 published measures:

01 Turning is Difficult	11 Effort of Turning	21 Continuous with Walking
02 Turns Effortlessly	12 Steps Backwards	22 Can Look Behind
03 Unsteadiness as Turns	13 Pivots when Turning	23 Number of Steps
04 Turns Regularly	14 Steps in an Arc	24 Weight-shifts Well
05 Turns Readily	15 Grabs, Staggers or Holds	25 Needs Supervision
06 Turn Time Slowing	16 Step Continuity	26 Able to Turn Safely
07 Ability to Turn	17 Sideways or Back Steps	27 Speed of Turning
08 Turns Very Slowly	18 Unsteadiness	28 Festinant Steps
09 Initiation of Turning	19 Turns Normally	29 Moves Forwards
10 Clumsy	20 Staggering	

From the Researcher's Video Analysis

The review was intended to generate descriptors based on the observation of people turning under controlled conditions. There were only 25 video-records to review, as:

- Men without PD (mean age 64) demonstrated three of the 12 Types (i.e. not all 12)
- Women without PD (mean age 62) demonstrated five of the 12 Types
- Women with PD (mean age 69) demonstrated eight of the 12 Types, and
- Men with PD (mean age 73) demonstrated nine of the 12 Types.

When the observations made on all 25 reports were amalgamated, eight dominant factors emerged, from which eight descriptors were extracted. Added to the 29 from the literature review, this brought the total number of descriptors identified to 37:

30 Stability	33 Ground Clearance	36 Head Rotation
31 Fluency	34 Arm Swing	37 Number of Steps
32 Base Width	35 Posture	

The video-analysis was undertaken because the records were collected under 'ideal' conditions. However, the participants were concentrating on the task and performing for the camera in an artificially hazard-free environment. As Yekutiel (1993) stressed, the motor-performance of people with PD can be very sensitive to context, so important aspects of turning may not have been demonstrated and hence not noted. The sample of records analysed was selected to reflect every turn-type identified in the original study by Ashburn et al (1998).

People with PD demonstrated the same Turn Types as people without PD plus some additional ones. Both men and women were observed, as it is possible that they turn differently. The video analysis required repeated viewing in slow motion as only one body part could be observed at any one time.

From the Therapy Research Group

The other therapy researchers generated further descriptors of turning from observing people turning functionally in their own homes. They identified six potential descriptors, four binary, one categorical and one continuous, bringing the total to 43:

38 Use of Support	40 Turn Type	42 Reduced Heel Strike
39 Apparent Instability	41 Number of Steps	43 Use of Space

The research group added another perspective. The videos that they reviewed showed people moving during a functional activity: turning occurred spontaneously rather than on command and turning was not the focus of the turner's concentration. The turns were 'realistic' i.e. the turner moved from a standing position performing one task to relocate himself or herself for the next.

From the Physiotherapists

The objective of seeking input from clinical physiotherapists was to generate further descriptors from the perspective of clinicians, highlighting factors that they might consider when assessing a patient. There were many similarities in the descriptors generated by the researchers and clinicians; overlap was considerable. The four clinicians listed 23 observations before and 19 observations after watching the video. Examples of their observations included: 'What happens with their arms during turning', 'Width of the loop they turn' and 'Distance feet are picked up from floor'. Their notes were summarised and 15 potential descriptors were discerned, bringing the total to 58:

44 Trunk Rotation	49 Heel Strike	54 Balance Reactions
45 Turning Circle	50 Turns Both Ways	55 Step Length
46 Posture and Head Rotation	51 Continuity	56 Needs Assistance
47 Time Taken	52 Can Turn	57 Foot Positions
48 Arm Swing	53 Foot Movement	58 Weight Transference

The clinicians identified several descriptors (e.g. trunk rotation, step length and weight-transference) which had not arisen elsewhere. It was only *after* watching the video that they made observations about foot contact with the floor e.g. 'swivelling on the foot', 'heel strike' and 'shift of stance foot', which suggests that the feet were a key focus of the therapists' visual attention. Each therapist contributed several descriptors, suggesting that the approach taken had facilitated communication.

From the People with PD

The final search for descriptors was intended to incorporate the perspectives of people who had experienced difficulty turning. In an earlier study (Stack and Ashburn, 1999) we quoted eight verbatim descriptions of difficulty turning:

- I have to take lots of short steps backwards when I turn, or I might fall
- All falls are to do with turns; your brain knows and your feet don't
- Your feet get tangled and you turn without moving
- Turning is a contributory factor in a lot of falls
- I turned quickly and my feet wouldn't move
- Your body turns and your feet don't
- Falls are all to do with turning
- Turning is fatal

The sub-sample of ten people from the Ashburn et al (2001) study gave the following responses to questions about turning:

- I try to make it a deliberate action but I still end up shuffling
- It's very difficult, especially indoors with tight corners
- The body doesn't go the way I want it to
- I'm frightened of turning around in case I fall
- I know if I'm not careful I could fall
- Sometimes I just can't turn round
- I am very slow with my trolley
- I twisel around on my feet
- Worst when I first get up
- I just freeze on the spot
- I concentrate more

These responses were summarised as pertaining to 1) freezing, feet sticking and decreased initiation of turning, 2) incomplete foot clearance, 3) speed, 4) fear, 5) the influence of the environment and 6) attention and concentration. Twelve descriptors were discerned from these accounts, which brought the final number of potential descriptors of turning to 70:

59 Attention	63 Decreased Initiation	67 Maintains Balance
60 Environment	64 Foot Clearance	68 Feet Get Tangled
61 Fearful when Turning	65 Speed of Turning	69 Feet Moved
62 Freezes or Feet Stick	66 Takes Several Steps	70 Loss of Balance

The quotes from people with PD were arguably more valid than any other set of descriptors. They outlined examples of the difficulties that the SS-180 will be used to evaluate, such as freezing and loss of balance. Further validity was added by having an independent researcher draw out themes from the hitherto unpublished data.

4.2.3 b The Short-listed Descriptors

Therapists with research experience were selected for the short-listing because of their experience in the measurement of movement. Only 20 of the 70 descriptors met both short-listing criterion i.e. they were considered to be among the most important aspects of turning and among the most readily measurable from a video-record by the researchers who considered them (**Table 4.1**).

Table 4.1. Short-listing of the 70 Descriptors

		Is the descriptor readily measurable from video?		
		YES	NO	TOTAL
Is the descriptor an important aspect of turning?	YES	**20**	08	28
	NO	11	**31**	42
	TOTAL	31	39	70

The descriptors that were short-listed are highlighted in **blue**.

Almost half of the descriptors (highlighted in **red**, above) were considered *both* unimportant and not readily measurable from video. Less than a quarter of the descriptors taken from the literature were short-listed. Five of the six descriptors that had originated from the research group were short-listed.

Clearly, the researchers still considered the descriptors that they had developed to be important and measurable; as such, using the same group of researchers at two points in the development of the SS-180 could be considered a weakness. The **20** descriptors, considered important and measurable, were:

Descriptors	Source
03 Unsteadiness as Turns 12 Steps Backward 15 Grabs, Staggers or Holds 21 Continuous with Walking 23 Number of Steps 27 Speed of Turning 28 Festinant Steps	Identified from the literature
33 Ground Clearance 35 Posture	Identified from the video analysis
38 Use of Support 39 Apparent Instability 40 Turn Type 41 Number of Steps 42 Reduced Heel Strike	Identified by the therapy researchers
47 Time Taken 49 Heel Strike 50 Turns both Ways 52 Can Turn	Identified by the physiotherapists
62 Freezes or Feet Stick 68 Feet Get Tangled	Identified by people with PD

No descriptors were removed before the list of 70 was compiled to avoid bias; whether or not two or more descriptors appeared to be virtually identical, they remained on the list. This made the list long and the short-listing laborious. For each short-listing criterion, the researchers were asked to section the list into approximate thirds; it is interesting that there was so little absolute agreement. Only two of the 70 descriptors ('*41: Number of Steps*' and '*62: Freezes / Feet Stick*') were considered important by all six researchers. Supplementary information provided about the value labels may explain why certain descriptors were short-listed while very similar descriptors were excluded.

The following example (**Table 4.2**) illustrates this possibility with reference to six descriptors all apparently describing *postural stability* during turning:

Table 4.2. Short-listing of Six Descriptors of Postural Stability

Descriptor		Short-listing Criteria Important	Measurable	Short-listed
Unsteadiness as Turns	- Yes or No	Yes	Yes	Yes
Apparent Instability	- Yes or No	Yes	Yes	Yes
Staggering	- Yes or No	**No**	Yes	**No**
Stability	- Steady, Cautious or Unsteady	Yes	**No**	**No**
Maintains Balance	- Yes or No	**No**	**No**	**No**
Loss of balance during Turning	- Falls, Nearly Falls or No	**No**	**No**	**No**

Descriptors relating to stepping dominated the shortlist, i.e. the number of steps, continuity and pattern of stepping, heel strike and ground clearance. Coupled with the observation that the clinicians only commented on stepping *after watching* people turn, this suggests that foot movement should be key in any turn-assessment tool.

4.2.3 c The Design of the SS-180

The SS-180 was designed from the 20 short-listed descriptors. The short-listed descriptors combined to form eight items, or variables. The items were then grouped and a new three-section outcome measure, the Standing-Start 180° Turn Test, was drafted.

Descriptors Combined		Item Formed
23 and 41	→	Turning Steps.
27 and 47	→	Turn Time.
12, 28 and 40	→	Turn Type.
38 and 52	→	Independence.
33, 42, 49 and 68	→	Clearance.
21 and 62	→	Continuity.
35	→	Posture.
3,15 and 39	→	Stability.

The remaining short-listed descriptor (*50: 'Turns Both Ways*'), was not incorporated into an item. Instead, the decision was made to rate two turns, one in each direction.

4.2.4 The SS-180: Format, Protocol and Analysis

4.2.4 a Format of the SS-180

Following discussions with professional and academic colleagues and revision during development (see Section 4.3) a final version of the SS-180 was established (**Figure 4.2**).

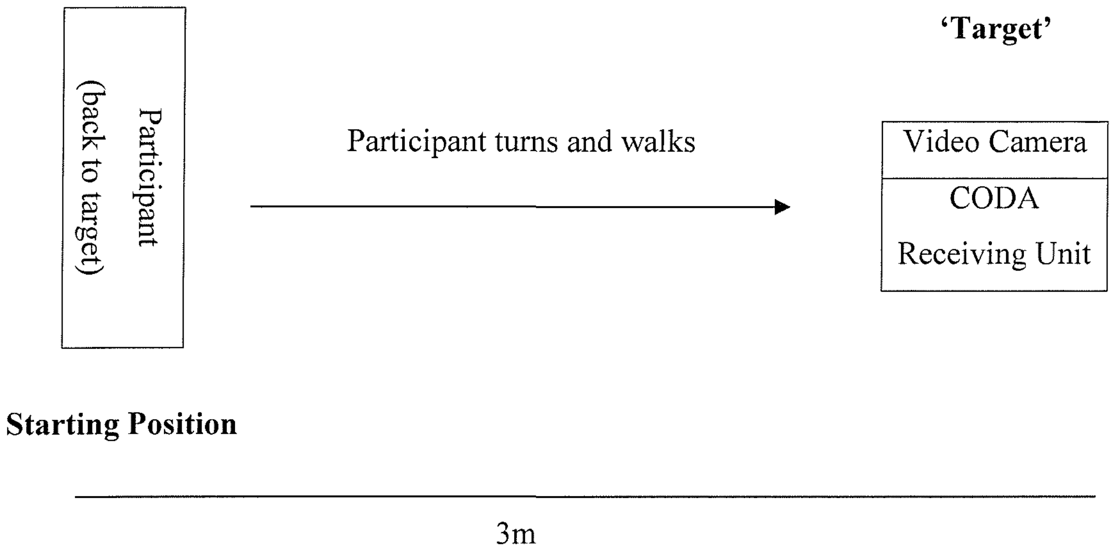
Figure 4.2. The Standing Start 180° Turn Test Scoring Form

Section 1		**1st Turn**	**2nd Turn**		
Item 1 Turning Steps	(n)			Mean	Change
Item 2 Turn Time	(sec)			Mean	Change
Section 2		**1st Turn**	**2nd Turn**		Same?
Item 3 Turn Type	Circle one	Delayed Incremental Pivotal Toward Lateral	Delayed Incremental Pivotal Toward Lateral		Y / N
Section 3		**1st Turn**	**2nd Turn**		Same?
Item 4 Independence	Yes 1 No 0				Y / N
Item 5 Clearance	Yes 1 No 0				Y / N
Item 6 Stability	Yes 1 No 0				Y / N
Item 7 Continuity	Yes 1 No 0				Y / N
Item 8 Posture	Yes 1 No 0				Y / N
		Total Turn Quality Score	Total Turn Quality Score	Mean	Change

4.2.4 b Protocol for Completion of the Test

The new measure requires the participant to demonstrate two turns from a standing start, one in an unspecified direction and one specified in the opposite direction. The set-up for the SS-180 is simple and is illustrated below (**Figure 4.3**).

Figure 4.3. The Gait Laboratory Set-up



The video camera for recording the performance of the test is set up with an unimpeded view of The Starting Position. The subject adopts The Starting Position; i.e. he or she stands with his or her back to the camera, facing away from the camera at a distance of approximately 2 or 3m from it. The camera position is The Target towards which the subject will walk when instructed so to do.

When in The Starting Position, the subject is given the instruction 'When you are ready, please walk towards The Target'. As the subject completes the first trial, the assessor must note the direction towards which he or she turned (see **Figure 4.4**).

When the subject has completed the first trial, he or she returns to The Starting Position and is asked to repeat the procedure. The subject is told towards which direction they had set off in the first trial and is asked to 'Make a point of going round the other way this time'. The same instruction is then given as in the first trial; 'When you are ready, please walk towards The Target'. The SS-180 is then complete.

Figure 4.4. A DU Turn (in this example a Toward Type Turn to the left).

a. Starting Position **b. Turning Step 1** **c. Final Turning Step**

4.2.4 c Rating the SS-180

The turn completed during the first trial, which was in a direction of the subjects free choice, is referred to as The Direction Unspecified (or DU) Turn. The turn completed during the second trial, which was in the opposite direction to the first turn, is referred to as The Direction Specified (or DS) Turn. Data should be entered in every box highlighted on the SS-180 scoring form. The rating of each item is made in accordance with the guidelines below. One observation of the video record will be required for each of the eight items rated. The DU Turn should be rated first, then the DS Turn.

Mean scores should be calculated for Turning Steps, Turn Time and the Total Turn Quality Scores (i.e. the total DU value plus the DS value divided by 2). Then, for these three items, the *change in value* when the direction of turning was specified should be calculated (i.e. DS value minus DU value). Finally, whether or not the DU and DS Turns differed in Turn Type and each of the individual Turn Quality items should be indicated on the form (see **Appendix 1** for visual representations of the Turn Types).

Rating Guidelines for the SS-180

Item and Definition	**Rating**
Turning Steps	
Foot movements that rotate the turner through 180° to face the target.	Count each foot movement as the subject turns. Do not count the first *walking step*, i.e. the first step toward the target that is predominantly unidirectional from toe-off.
Turn Time	
The time from the initiation to the completion of the turning steps.	Start the watch when the first turning-step begins. Stop the watch when the last turning-step is complete. Take the mean of five timings.
Turn Type	Choose which definition best fits the turn observed:
Delayed Onset	At least four turning steps; though may be many more. The initial turning-step with each foot makes negligible progress toward the target or in changing direction.
Incremental	Turning 'on-the-spot' before advancing to the target.
Pivotal	Completed in 2 or 3 turning-steps. Initial step wider than it is long, followed by a second wide step.
Toward	Complete in 2 turning-steps. First foot moved is always the same side as the direction of turn. Direct advance toward the target with negligible lateral deviation.
Lateral	Complete in 2 or 3 turning-steps. First foot moved is always the opposite side to the direction of turn.

Turn Quality Score	A composite score describing the subjects as they turn
Independence Turning without *any* assistance.	Did the turner require external support, a walking aid or the assistance of another person (*physical or verbal*) as they completed the turn? If so, score 0; otherwise score 1.
Clearance Both feet clearing the floor *and* each other when turning.	Did both feet clear the floor and each other throughout the entire turn, except when pivoting to change direction during one turning step? If so, score 0; otherwise score 1.
Continuity The turn being an integral part of progress to the target.	Was there a pause during or after turning before walking toward the target? If so, score 0; otherwise score 1.
Posture Maintaining the upright stance when turning.	Did the subject become clearly more flexed during turning than when they began the test; did they lower their height? If so, score 0; otherwise score 1.
Stability Appearing stable and not at risk of falling when turning.	Did the subject appear unstable or at risk of falling when turning; did they or the person in attendance make any saving reactions? If so, score 0; otherwise score 1.

Presentation of Data

When the SS-180 has been completed, the following four statistics can be presented, to give a succinct evaluation of the standing-start turns demonstrated:

- Mean Turning Steps
- Mean Turn Time
- Turn Types Demonstrated, and
- Mean Turn Quality Score

4.3 Early Development of the SS-180

The video-based SS-180 was designed to facilitate research on dysfunctional turning in settings other than a gait laboratory. Turning Steps and Turn Time (Section 1), Turn Type (Section 2) and Turn Quality (Section 3) are all rated from the video record. In this section, the first steps toward establishing the validity and reliability of the new tool are outlined. These investigations were important steps in the early development of the tool but, in using any instrument, estimates of its validity and reliability are constantly refined. Therefore, the issues raised here will be discussed further in later chapters.

4.3.1 External Validity

This study was conducted to demonstrate whether or not the results obtained from a video-based analysis of the SS-180 were comparable with results obtained using an expensive 'gold standard' laboratory-based motion analysis system. Ratings from video of Turning Steps, Time and Type were compared with ratings from an available criterion measure, CODA (Computerised Optoelectronic Dynamic Anthropometry), a three-dimensional motion tracking system, made by Charnwood Dynamics of Leicestershire. There is no available data with which to compare the results as, although external validity is a key requirement of a measurement tool, none of the authors who have published observational assessments of turning (i.e. Tinetti et al (1986), Lipsitz et al (1991), Berg et al (1992), Schenkman et al (1996), Ashburn and Stack (1999), Suteerawattananon and Protas (2000), Thigpen et al (2000), Stack et al (2001) Simpson et al (2002), in Chapter Three) have tested their tools (or any part of their tools) against an external criterion measure.

In this method comparison study, one section of the SS-180 (Turn Quality) could not be rated from CODA. One appropriate criterion measure for the constituent items of this section would be the consensus opinion of an expert panel. Clearly, as the SS-180 was a) a new test, b) in the process of development and c) used hitherto only by the test developer, an expert panel was not an available option. The tool developer would have had to have trained the 'experts' against whom the developer's video analysis was to be validated: this would have been entirely inappropriate.

4.3.1 a Methods

Participants

The participants whose data were used in this validity study were a sub-sample of those healthy adults and people with PD who took part in the laboratory-based studies discussed later in Chapters Five and Six: recruitment details are presented in those chapters. The records of five people with PD who completed the laboratory-based studies and five healthy adults were used to validate the *Turn Time* rated by the researcher from video against that rated from CODA. The records of a further 20 participants who completed the test were used to validate *Turning Steps* and *Turn Type*.

Procedure

The participants completed the SS-180 following the protocol stated above, in Section 4.2.4. Their performances were recorded using both video and CODA. The video camera and the CODA scanner unit were positioned in the target area towards which the participants were required to walk during the test. The camera was positioned directly on top of the scanner so that both instruments were recording the participants' movements from the same direction.

Instruments

The video camera (a Sony Handycam) was turned on before the participants were given their instructions and was then left to record throughout the test.

The CODA mpx30 scanner (or measurement unit) contains three cameras that track the position of active markers (infrared light pulse-emitting LEDs). The scanner requires an unimpeded view of the markers and their power packs, without which (rotated to the limits of their angular field) the markers disappear from view. When the system is acquiring data, the sensor logs the position of each marker many times every second (for approximately 40 μs). The sampling rate (200 samples per second in this study) depends on the number of markers being tracked and the maximum measurement time (15 seconds in this study) depends on the sampling rate. At 3 metres, the lateral position resolution is 0.1mm and the distance resolution is 0.6mm. Resolution has been reported by Mitchelson (1990) to be 0.1mm in the X and Y planes and 0.01mm in the Z plane.

The measurement volume (distance, width and height) extends from 2.5m to 6m in front of the measurement unit. The long axis of the measurement unit defines the X-axis (parallel to the walkway). The Y-axis is across the walkway and the vertical defines the Z-axis. The user sets the origin of the co-ordinate system and the measurement unit is connected to the host PC. The cost of the CODA mpx30 system used was approximately £60,000. The CODA system was set up in advance of the participant entering the laboratory, i.e. the markers checked for charge, a data storage file opened, the position of the origin from which the scanner unit would take measurements defined, and the markers prepared. The set-up used encompassed four markers, sampled at 200 Hz for 15s, to track the position of the participants' feet throughout the test. Two markers were attached to each shoe, one on the midline of the heel and one over the great toe. The recording of each turn commenced on the word 'Ready' in the instruction 'When you are ready, please walk towards the target'. The markers were left in position throughout the session, so that they were in the same position during both the DU and DS Turns.

Evaluating the Turns

The researcher rated Turning Steps, Turn Time and Turn Type from the CODA output. A Turning Step was counted every time the markers from one foot were repositioned in space while the markers from the other foot indicated that foot to be on the floor. The final Turning Step was taken to be the step preceding the onset of a pattern of toe marker movement indicative of straight forward gait toward the target. The heel markers were lost from view by that point. Turn Time was calculated from the onset of the first Turning Step counted to the onset of the first straight forward step to the target identified. The magnitude and direction of each Turning Step generated was ascertained, i.e. the movement of the markers from their starting positions and the most appropriate Turn Type definition selected (see **Appendix 1**). At the point in time at which this study was undertaken, six Turn Types had been defined. One Type missing from the final version of the SS-180 was an *'Away'* Turn, defined as movement of both feet away from the target before advancing toward it. The researcher also timed the turns from video, in accordance with the rating guidelines in Section 4.2. An independent, trained researcher was asked to rate the Turning Steps and Turn Types demonstrated from video. An independent researcher was used because there was a possibility of the lead researcher being biased in rating Turning Steps and Turn Types from video by her experiences of rating them from CODA. The independent researcher was trained on a different subset of videos than that which was used in the validity study.

Comparing Video with CODA

Two methods for comparing the ratings were used. Agreement with respect to categorical data was estimated using the Kappa measure of agreement, as recommended by Altman (1991) and agreement with respect to continuous data was estimated using the method described by Bland and Altman (1986).

The first step towards calculating a Kappa value was to cross-tabulate the rating given by both methods and distinguish the number of exact agreements observed. A percentage of exact agreement was calculated from this number divided by the total number of paired-observations. Further calculations were necessary to estimate the agreement that was over and above that expected by chance. The chance agreements were calculated by summing the expected frequencies of the cells in the cross-tabulation. The agreement between methods was then expressed as a proportion of 'the scope for doing better than chance'. The Kappa value (*k*) lies between zero and one, i.e. between agreement that is no better than chance and perfect agreement. A standard error and confidence interval for *k* was also calculated. For ordinal data, a Weighted Kappa value (*kw*) was calculated. By giving weights to the magnitude of any discrepancies between ratings, those nearer to agreement could be 'considered less serious' than those where the discrepancy was larger. Landis and Koch (1971) suggested guidelines for interpreting *k* values:

***k* value**	**Agreement**
< 0.20	Poor
0.21 – 0.40	Fair
0.41 – 0.60	Moderate
0.61 – 0.80	Good
0.81 - 1.0	Very Good

As Altman (1991) emphasised, 'real data never agree exactly', or they would lie right on the line of equality in a scatter plot. For this reason, correlating two measurements was an inappropriate way of evaluating agreement: plotting the difference between the measurements against the mean of the two was more informative. In such a plot, the mean acted as the best estimate of the true value. The plot was examined to assess whether the differences appeared to be related to the size of the measurement. The standard deviation of the differences was used to delineate those values that would cover the agreement between the methods in most cases. The mean ± 2 standard deviations of the difference defined the 95% limits of agreement.

4.3.1 b Results

To validate Turning Steps and Turn Type, the turns of 20 participants were rated from video but due to a fault with one of the CODA markers only 19 of the participants' records could be analysed. As each performance of the SS-180 necessitated two turns, the video and CODA ratings of a total of 38 turns were compared. The sample consisted of ten men and nine women, ranging in age from 27 to 83 years (with a median age of 40 years). For the external validation of Turn Time, the sample consisted of five healthy adults (four women) ranging in age from 28 to 41 years (median 30 years) and five people with PD (three men) ranging in age from 69 to 85 years (median 77 years), Hoehn and Yahr Grades II-IV.

Agreement on Turning Step Count

The distribution of Turning Step counts in the sample made the Weighted Kappa (K_w) value a more appropriate way of demonstrating agreement than the Bland and Altman (1986) technique: although data were continuous, they took only three values. **Table 4.3a** cross-tabulates the Step Counts rated from video and CODA; the 27 exact agreements (accounting for 71% of the 38 turns rated) are highlighted in **blue**. There was a discrepancy of one step between the ratings of the remaining 11 turns. The overall agreement between the methods was moderately close (*kw* 0.57) and better than would be expected by chance.

Table 4.3a. External Validity: Turning Step Counts

		Rating from VIDEO			
	Steps (n)	**2**	**3**	**4**	**Total**
	2	19	1	-	20
Rating from CODA	**3**	8	7	-	15
	4	-	2	1	3
	Total	27	10	1	38

Agreement between the two methods of rating Turning Steps was better for DU Turns than DS Turns. For DU Turns, there was exact agreement on 15/19 (79%, *kw* 0.72) and for DS Turns there was exact agreement on 12/19 (63%, *kw* 0.56). On inspection of the discrepancies, it was apparent that in ten cases (highlighted in **red** in the table) the video rating counted one step less than did the CODA rating. Therefore, the definition of a Turning Step was modified in an attempt to improve clarity and agreement.

When the analysis of the 38 turns was repeated using the modified definition, the overall agreement between the methods was very good (*kw* 0.86). The 35 exact agreements (accounting for 92% of the 38 turns rated) are highlighted in **blue** in **Table 4.3b**.

Table 4.3b. External Validity: Turning Step Counts with Modified Definition

		Rating from VIDEO			
	Steps (n)	**2**	**3**	**4**	**Total**
	2	**18**	2	-	20
Rating from CODA	**3**	-	**15**	-	15
	4	-	1	**2**	3
	Total	18	18	2	38

For DU Turns, there was exact agreement on 18/19 (95%, *kw* 0.91) and for DS Turns there was exact agreement on 17/19 (89%, *kw* 0.79). The definition given in the Rating Guidelines (Section 4.2) is the modified version, amended during development and used in the studies described in the following chapters.

Agreement on Turn Time

Healthy Adults

In **Figure 4.5**, the differences between the measurements are plotted against the mean of the two. The differences did not appear to be related to the size of the measurement and the mean difference (0.02s ± 0.24s) was very small, i.e. 'the methods agree excellently on average'. The 95% limits of agreement in this case ranged from –0.46s to +0.50s: one would expect the two methods to give measurements that differed by less than 0.5s.

People with PD

In **Figure 4.6**, the differences between the measurements are plotted against the mean of the two. The scatter increasing with the mean as it does (indicating variable agreement) was a problem. In this case, taking logs (i.e. considering the differences as proportions of the measurement) allowed a better analysis. The analysis was performed on logarithmically transformed data, which back-transformed gave the result. The mean of the logged differences was -0.03s (± 0.03). When back-transformed, the geometric mean of the difference was 0.9s. The 95% limits of agreement were then expressed as a proportion. A CODA timing was likely to lie between 20% below and 7% above that timed from video.

Figure 4.5. Differences between Times rated from Video (VT) and CODA (CT) against the means of the ratings for five healthy adults (95% limits of agreement are dotted).

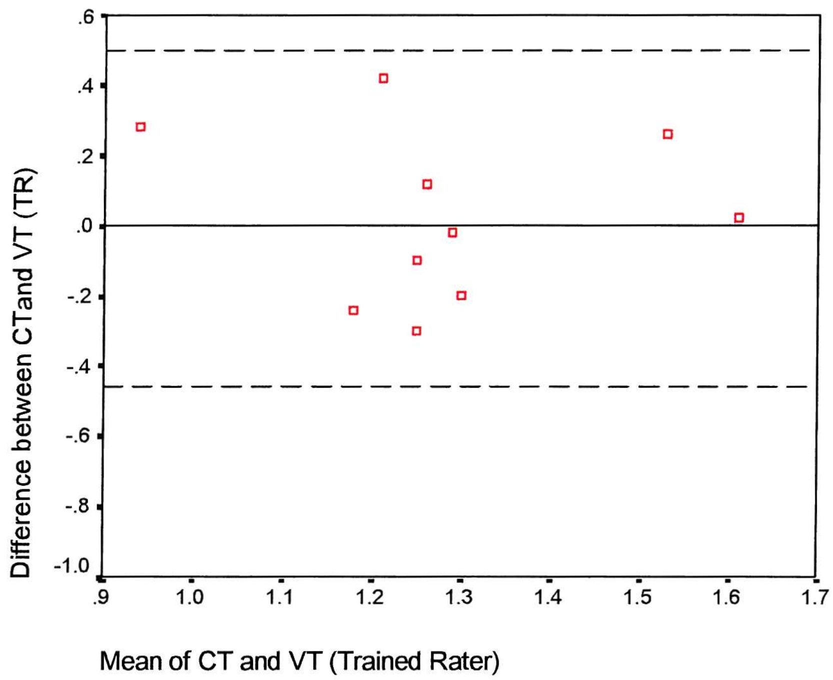
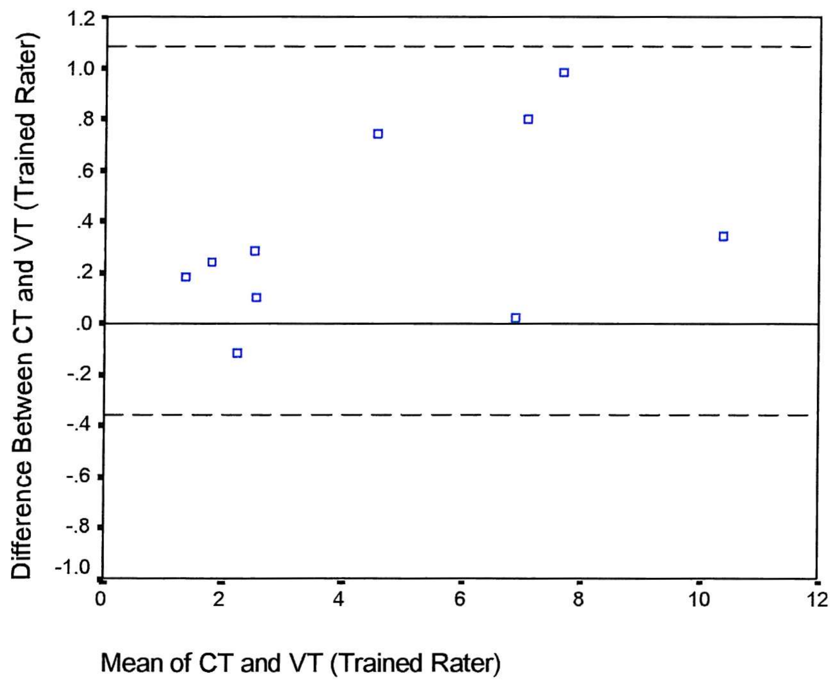


Figure 4.6: The differences between Turn Times rated from Video (VT) and CODA (CT) plotted against the means of the ratings for five people with PD.



Agreement on Turn Type

Table 4.4 cross-tabulates the Turn Types rated from video and CODA. The 32 agreements (accounting for 84% of the turns rated) are highlighted in **blue**. The overall agreement between the methods was good (*k* 0.78, 95% CI 0.70 to 0.86) and better than would be expected by chance.

Table 4.4. External Validity: Turn Type

		Rating from VIDEO					
	Type	**Incremental**	**Pivotal**	**Toward**	**Away**	**Lateral**	**Total**
	Incremental	1	-	-	-	-	1
Rating	**Pivotal**	-	14	1	-	-	15
from	**Toward**	-	-	11	-	-	11
CODA	**Away**	2	1	-	-	1	4
	Lateral	1	-	-	-	6	7
	Total	4	15	12	0	7	38

Agreement between the two methods of rating Turn Type was similar for the DU and DS Turns. For DU Turns, there was agreement on 16/19 (84%, *k* 0.78) and for DS Turns there was also agreement on 16/19 (84%, *k* 0.76). On inspection of the discrepancies, it was apparent that in five cases (**red** in the table) the discrepancy involved a Turn Type categorised as *Incremental* or *Away*. The decision was made to merge the two Turn Type definitions in an attempt to improve clarity and agreement. As with Turning Steps, the definitions given in the Rating Guidelines (Section 4.2) are the modified versions, amended during development and used in the studies described in the following chapters.

4.3.1 c Conclusions

In conducting a preliminary study of this kind, one posed the question 'do the methods agree well enough for one to replace the other' (Altman, 1994)? In other words, did the simple rating of Turning Steps, Time and Type from video generate findings comparable to those generated by an accepted external criterion? In completing these method comparisons, a different sample of video records was used to validate Turn Time than was used to validate Turning Steps and Type. This allowed the requisite training to be conducted using a different set of videos than was used to reach the estimate of agreement: using the *same* set of videos for training and validation would have given estimates of agreement that were misleadingly high. In this case, the data from ten participants was used to externally validate Turn Time before those video records were used for training purposes. The available data from the remaining participants was used to validate Turning Steps and Type. The data set available was small and, as stated previously, none of the authors who have published observational assessments of turning have tested any part of their tools against an external criterion. These limitations must be taken into account when interpreting the findings. Despite these caveats, video-rating the SS-180 produced results acceptably comparable with a laboratory-based gold standard:

- Agreement counting Turning Steps from video and CODA was very good (*kw* 0.86) after the Turning Step definition was modified in light of the first attempt to compare the methods revealed only moderate agreement (*kw* 0.57).

- The mean difference in Turn Time rated from video and CODA was 0.02s in the sample of healthy adults tested and 0.9s in the sample of people with PD.

- Agreement on Turn Type rated from video and CODA was good (*k* 0.78); two Turn Type definitions were merged in light of this finding.

Refinement of the estimates of validity would be expected when the SS-180 is used in further studies and, more importantly, when the tool is used by other researchers, at which time the need to demonstrate the external validity of Turn Quality can also be addressed.

4.3.2 Intra-rater Reliability

The objective was to establish the reliability with which the researcher rated the video-based SS-180. All three sections of the SS-180 (Turning Steps and Turn Time, Turn Type and Turn Quality) were suitable for estimation of the intra-rater reliability.

4.3.2 a Methods

Participants

The sample consisted of ten people selected at random from among the people who participated in the laboratory-based studies (Chapters Five and Six).

Procedure

The participants completed the SS-180 following the protocol stated in Section 4.2. One turn by each participant was rated from video twice by the researcher, with an interval of one week between ratings. The Kappa measure of agreement and the method described by Bland and Altman (1986) were used to compare the ratings, as in Section 4.3.1.

4.3.2 b Results

The sample consisted of ten people. The three with PD ranged in age from 72 to 85 years and were at Hoehn and Yahr Grades II and III. The seven without PD (two men and five women) ranged in age from 21 to 54 years (with a median of 32 years).

Turning Step Count, Turn Type and Turn Quality Score

As shown in **Tables 4.5 to 4.7** (with exact agreements **highlighted**), the two ratings of Turning Steps, Turn Type and Turn Quality Score were in 100% agreement.

Table 4.5. Intra-rater Reliability: Turning Steps

		Second Rating (Week 2)				
Steps (n)		2	3	5	15	Total
	2	4	-	-	-	4
First	3	-	4	-	-	4
Rating	5	-	-	1	-	1
(Week 1)	15	-	-	-	1	1
	Total	4	4	1	1	10

Table 4.6. Intra-rater Reliability: Turn Type

	Types (n)	Second Rating (Week 2) Incremental	Pivotal	Toward	Lateral	Total
First Rating (Week 1)	Incremental	2	-	-	-	2
	Pivotal	-	2	-	-	2
	Toward	-	-	3	-	3
	Lateral	-	-	-	3	3
	Total	2	2	3	3	10

Table 4.7. Intra-rater Reliability: Turn Quality Scores

	Scores	Second Rating (Week 2) 3	4	5	Total
First Rating (Week 1)	3	1	-	-	1
	4	-	3	-	3
	5	-	-	6	6
	Total	1	3	6	10

Turn Time

The mean Time difference between ratings was -0.12s (± 0.09s); 95% limit of agreement from –0.30s to 0.06s, see **Table 4.8**.

Table 4.8. Intra-rater Reliability: Turn Time

Week One Rating 1 (s)	Week Two Rating 2 (s)	Mean Time (s)	Time Difference (s)
1.50	1.40	1.45	-0.1
1.40	1.20	1.30	-0.2
1.40	1.00	1.20	-0.3
1.10	1.00	1.05	-0.1
1.70	1.70	1.70	0.0
1.80	1.80	1.80	0.0
6.90	6.80	6.85	-0.1
2.50	2.30	2.40	-0.2
1.30	1.20	1.25	-0.1
1.60	1.50	1.55	-0.1
			Mean 0.12 (±0.09)

4.3.2 c Conclusions

The Intra-rater reliability proved acceptable with respect to all three sections of the new measures.

4.3.3 Inter-rater Reliability

The objective of this study was to establish the reliability with which the researcher and another trained researcher rated the video-based SS-180. All three sections of the SS-180 were deemed suitable for estimation of the inter-rater reliability.

4.3.3 a Methods

Participants

The same set of video records used to estimate intra-rater reliability was used in this study, i.e. those of three people with PD and seven without (see Section 4.3.2).

Procedure

Participants completed the SS-180 following the protocol stated in Section 4.2. The turns were independently rated from video by the researcher (the first rating in the intra-rater reliability study) and by a second, trained researcher. The Kappa measure of agreement and the method described by Bland and Altman (1986) were used to compare ratings.

4.3.3 c Results

Turning Step Count, Turn Type and Turn Quality Score

Agreement was good for Step Count (*k* 0.70), with exact agreement on eight of the ten turns rated (80%) and a one-step discrepancy on two turns. There was 100% agreement on Turn Type. Agreement on Turn Quality Score was very good (*k* 0.82), with exact agreement on nine turns (90%) and a one-point discrepancy on one.

Table 4.9. Inter-rater Reliability: Turning Steps

	Steps (n)	Second Rater 2	3	5	15	Total
	2	**3**	1	-	-	4
First	3	1	**3**	-	-	4
Rater	5	-	-	**1**	-	1
	15	-	-	-	**1**	1
	Total	4	4	1	1	10

Exact Agreements are **highlighted**.

Table 4.10. Inter-rater Reliability: Turn Quality Scores

	Scores	Second Rater 3	4	5	Total
	3	**1**	-	-	1
First	4	1	**2**	-	3
Rater	5	-	-	**6**	6
	Total	2	2	6	10

Exact Agreements are **highlighted**.

Turn Time

The mean Time difference between raters was 0.03s (± 0.23s); 95% limit of agreement from –0.42s to 0.48s, see **Table 4.11**.

Table 4.11. Inter-rater Reliability: Turn Times

Rater 1 (s)	Rater 2 (s)	Mean Time (s)	Time Difference (s)
1.50	1.30	1.40	-0.2
1.40	1.50	1.45	0.1
1.40	1.70	1.55	0.3
1.10	1.20	1.15	0.1
1.70	1.30	1.50	-0.4
1.80	2.10	1.95	0.3
6.90	7.10	7.00	0.2
2.50	2.60	2.55	0.1
1.30	1.20	1.25	-0.1
1.60	1.50	1.55	-0.1
			***Mean* 0.03 (± 0.23)**

4.3.3 d Conclusions

The Inter-rater reliability of all three sections of the new measure proved acceptable.

4.3.4 Test-retest Characteristics

People with PD are subject to considerable fluctuations in their motor performance. Research on straight forward gait has shown that repeated measures (including speed, cadence, stride length and double-support time) taken at peak dose are most reliable, whilst repeatability from peak dose to end-of-dose is extremely poor (Morris et al, 1996). Morris et al found little variation in any of the gait variables measured in a sample of 16 people with PD during the 'on phase'. Schenkman et al (1997) reported similar findings with respect to turning at peak dose; they demonstrated acceptable test-retest reliability among a sample of 14 people with PD performing 360° turns, for both Step Count and Time. Although the SS-180 is in the early stages of development, a full evaluation of the tool would necessitate taking an approach like that taken by Morris et al, i.e. describing:

1. Repeatability of the SS-180, two and 30 minutes apart at peak dose
2. Difference between peak dose measures on consecutive days
3. Effect of medication on turning: repeatability from peak- to end-of-dose, and
4. Stability of the SS-180 throughout the on phase.

As the intention in the studies that follow was to have people demonstrate the SS-180 only once (midway between doses), it was important to establish whether a one-off performance of the test was reflective of the way in which the participant would turn again, given another attempt. Simpson et al (2002) found no evidence of a consistent learning effect with their TURN180 Test. If significant differences were identified on repeating the SS-180, it would have been necessary to ensure that a suitable number of trials were completed by each participant and analysed, to allow for the variation in test performance. The objective of this study was to establish the test-retest characteristics of all three sections of the SS-180.

4.3.4 a Methods

The test-retest characteristics were established by testing seven participants (four with PD) twice. Participants completed the SS-180 following the protocol stated in Section 4.2. After a break but within the same session, the participants repeated the test.

4.3.4 b Results

The participants with PD ranged in age from 63 to 77 years and were all at Hoehn and Yahr Grade III. The participants without PD ranged in age from 44 to 52 years. The results are summarised in **Table 4.12**. In the *Participant ID* column, healthy adults are given the identification letter H and people with PD are identified by the letter P. Each column headed ***T*** indicates the performance on the first test, whereas each column headed ***RT*** indicates the performance on re-testing. Columns headed by the letter ***C*** indicate the change from testing to re-testing. Taking the sample as a whole, the median Turning Step count was one less on re-testing, the turn completed a median of 0.2s faster than before, the Turn Type never changed and the median change in Turn Quality Score was zero (the change never being greater than one point).

Table 4.12. Test-retest Characteristics of the SS-180

	Turning Steps			Turn Time (s)			Turn Type			Quality		
ID	T	RT	C	T	RT	C	T	RT	C	T	RT	C
H1U	2	2	0	1.3	1.3	0	Toward	Toward	No	5	5	0
H2U	3	3	0	1.7	1.5	-0.2	Lateral	Lateral	No	5	5	0
H3U	3	3	0	1.4	1.2	-0.2	Lateral	Lateral	No	5	5	0
H1S	2	2	0	1.2	1.2	0	Toward	Toward	No	5	5	0
H2S	3	3	0	1.7	1.6	-0.1	Lateral	Lateral	No	5	5	0
H3S	3	3	0	1.4	1.1	-0.3	Lateral	Lateral	No	5	5	0
P1U	15	14	-1	6.7	6.9	0.2	Incremental	Incremental	No	4	4	0
P2U	7	6	-1	3.9	3.1	-0.8	Incremental	Incremental	No	3	4	1
P3U	5	3	-2	2.5	1.2	-1.3	Incremental	Incremental	No	3	4	1
P4U	6	5	-1	3.3	3.1	-0.2	Incremental	Incremental	No	5	4	-1
P1S	31	17	-14	10.4	7.5	-2.9	Delayed	Delayed	No	2	3	1
P2S	5	4	-1	2.3	2.1	-0.2	Incremental	Incremental	No	4	4	0
P3S	5	4	-1	2.3	2.0	-0.3	Incremental	Incremental	No	5	5	0
P4S	6	4	-2	3.7	2.3	-1.4	Incremental	Incremental	No	5	5	0

Changes on Re-testing are highlighted.

When re-tested, people *without* PD turned a mean 0.1s faster than before (95% limit of agreement from –0.4s to 0.1s); otherwise they turned as they had done when first tested. When re-tested, people *with* PD took a median one step less than before. They turned a mean 0.9s faster than before (95% limit of agreement from –2.8s to 1.1s); a median change of 0.6s. The Turn Type did not change and Turn Quality never changed more than one point either way, with a median of zero change.

The relatively large mean change in Turn Time in the PD group (-0.9s (± 1.0s) can be explained by one participant who demonstrated a much slower DS turn than anyone else (10.4s), even when re-tested (7.5s). If that one data set is removed, the mean change on re-testing in the remaining seven Turn Times is just -0.6s (± 0.6s), with 95% limit of agreement from –1.8s to 0.6s.

4.3.4 c Conclusions

The findings of this small study must be interpreted cautiously as the number of participants was small (only 14 turns were repeated) but they suggested that the first performance of the SS-180 was likely to be representative of a repeat performance minutes later. The implication of this conclusion was that, in the studies to follow, participants would only be asked to perform the SS-180 once.

The test-retest differences calculated above include the data from all four participants with PD. In the case of the individual who demonstrated a Delayed Onset Type Turn, however, the repeat performance was markedly different and caution should be applied when considering whether any single performance of a Delayed Onset turn can be considered representative. Further evaluation of test-retest stability is indicated for future study, with a larger sample of participants. In particular, further exploration of Delayed Onset Turns is necessary; it may be that such turns are by definition less likely than the other Turn Types to be performed consistently.

Differences in turning from one day to the next and throughout the drug cycle and the on phase remain to be investigated, although there is clearly a need to do so. The limits of a PhD thesis prevented these qualities of the SS-180 from being explored at this stage, unlike external validity and intra- and inter-rater reliability which were deemed essential prerequisites before using the new test to collect data.

4.4 Discussion

4.4.1 Design of the SS-180

Turning is a complex activity but to facilitate 1) its description, 2) appropriate research and 3) the communication of findings, it was necessary to identify a simple protocol for testing and evaluating performance. With nothing suitable in existence, a new tool was designed. The three-stage design process culminated in discerning the most appropriate descriptors of turning, gleaned from a wide-ranging search in the field of PD, and constructing the SS-180. The evaluation of a turn from a standing-start was chosen as it has greater ecological validity than the evaluation of walking 180° turns or 180° or 360° turns 'on-the-spot'. At the very least, the test will facilitate standardised description of an individual's or group's ability to perform standing-start turns. Furthermore, it is envisaged that the combination of items rated, in conjunction with appropriate other measures, will suggest answers to a number of outstanding questions pertaining to dysfunctional turning in PD.

The final number of items to be rated after each turn (i.e. eight) is not overwhelming in the immediate research context. However, the interests of a trained researcher with the resources to systematically review video records might be very different to those of a busy clinician. Further simplification in rating the SS-180 would be apposite before the tool could be advocated for routine clinical application. With use, and when data has been examined, it may, for example, be appropriate to reduce the item number further by eliminating any that appear superfluous or redundant.

4.4.2 Validity and Reliability of the SS-180

Validity and reliability are not absolute but rather are relative qualities; in developing tools, researchers decide what levels can be considered acceptable rather than aim for benchmarks 'set in stone'. The preliminary validation and reliability studies demonstrated that the SS-180 had the potential to be used in the investigations for which it was intended.

In externally validating the SS-180, 'true' values were not known; only the video rating and CODA ratings were known. The Turning Step counts were compared and the findings used to optimise agreement between the tools, one newly designed and one considered the 'gold standard'. Agreement was acceptable and good agreement is only achieved if both measures are reliable. With the finalised definition of a 'Turning Step', the researcher was consistent in counting from video and a second researcher's counts were in acceptable agreement. People invited to repeat the SS-180 showed that the number of Turning Steps taken during the session changed minimally, if at all, in the majority of cases. Again, all that was known of Turn Time was the video rating and the CODA rating; these were compared and agreement deemed acceptable. Agreement was best when turning was complete in fewer than four seconds. The researcher was consistent in timing from video and a second researcher's timings were in acceptable agreement.

The healthy adults who repeated the SS-180 showed consistent Turn Times: allowing for measurement error, no change could be detected between the tests and re-tests. The people with PD turned slightly faster than they had done before when they were re-tested. Agreement between the video and CODA ratings of Turn Type was acceptable. Working with the finalised Turn Type definitions, the researcher was consistent in rating from video and the second researcher's ratings were consistent with those of the lead researcher. The people invited to repeat the SS-180 all repeated the same Turn Type. With regard to the scoring of the final part of the SS-180 (Turn Quality), the researcher was consistent in rating from video and a second researcher's counts were in acceptable agreement. People invited to repeat the SS-180 showed that the Turn Quality Score changed minimally, if at all.

A caveat to these conclusions is that estimates of validity depend on the nature of the sample and the circumstances surrounding the assessment. 'Every time a scale is used in a new context, or with a different group of people it is necessary to re-establish its properties' (Streiner and Norman, 1995). In using the SS-180 in other settings and with more varied samples, a greater understanding of its characteristics will develop. The samples used in these preliminary studies were small. This may have contributed to the finding that although the mean differences quoted for Turn Time were small, the confidence intervals were wide. However, the samples encompassed a range of ages, both sexes and people with and without PD.

4.4.3 Strengths and Weaknesses of the Measure

The number of test protocols already used to evaluate turning (e.g. *walking turns* and turns *'on-the-spot'*) has been raised as a criticism of the literature and the creation of a *standing-start* turn test introduces one more protocol. However, one of its strengths is that the SS-180 was designed specifically for the evaluation of a functionally relevant style of turning among people with PD. As the test is original, the first results will not be easily comparable with other research findings.

Developed with people with PD in mind, the SS-180 encompasses pertinent aspects of the dysfunctional turning associated with the condition. The item definitions have been refined following early exploration of their validity and reliability, to optimise clarity. Another strength of the measure is that there is no requirement on the part of the rater to judge 'normality'. The constituent items were distilled from among many potential descriptors: only those considered important and measurable by a group of experienced researchers were incorporated into the new tool, conferring on it a degree of face validity.

The SS-180 is quick to complete and requires little space and equipment; detailed guidelines for its completion and evaluation have been written. Performance must be rated from a video record, as the eight items to be rated each require at least one observation. Therefore, a test taking one minute can take fifteen minutes to evaluate. In the following four chapters, the SS-180 is used to measure turning in a series of studies involving people with and without PD in a laboratory and beyond.

Chapter Five

Movements used by Healthy Adults during the Standing-start 180° Turn Test

5.1 Introduction

Turns from a standing start have not been described in a standardised manner before. With the development of the Standing Start 180° Turn Test it has become possible to describe this manoeuvre systematically and reliably. Understanding more about the requirements of this activity and how it is ordinarily accomplished by healthy adults is a step towards understanding some of the difficulties encountered by people with PD when attempting what is, to them, a notoriously challenging manoeuvre. The study described below was the first investigation in which the SS-180 was utilised and can be considered a step in the development of the new measure. This study was conducted in a laboratory, so that the set-up would be relatively constant and additional measurements of the standing-start turn could be made using some of the motion-analysis tools not available beyond the laboratory. These additional measures were of the starting positions adopted by the participants (lateral heel separation and the anterior-posterior difference) and the magnitude of the Turning Steps demonstrated (width, or movement in the frontal plane, and length, or anterior-posterior progress toward the target).

5.1.1 Objectives

a) To describe how healthy adults turn from a standing-start.
b) To determine the spatial parameters of the Turn Types demonstrated.
c) To identify any relationships between the performance of the SS-180 and age, gender, balance control and hand dominance.

5.2 Methods

5.2.1 Recruitment

Permission to conduct the study was given by the Local Research Ethics Committee (**Appendix 2**). A convenience sample of healthy adults was recruited, including (but not limited to) staff and students from the University of Southampton. Potential participants were approached in person and informed about the study. To be eligible to participate, the volunteers had to be 18 years of age or older, without a diagnosis of PD and unaware of any deficit currently impeding their mobility or balance, e.g. acute back pain or a recently sprained ankle. They were required to give written consent to participate.

5.2.2 Procedure

For each participant, data collection took place in one session in the Gait Laboratory at Southampton General Hospital. Age and Sex were recorded. Height (in cm) was measured with the participants dressed, as they would be for the completion of the SS-180, i.e. wearing outdoor shoes. Functional Reach (FR, measured in cm) is a reliable, precise and stable measure of dynamic balance (Duncan et al 1990; Thapa et al 1994; Giorgetti et al 1998); performance in the clinical setting is comparable with performance in the home (West et al, 1997). Forward Functional Reach in standing was measured three times with the dominant hand and the mean of the three reaches calculated. So that participants of different heights could be compared meaningfully, Height-adjusted FR or FR as a percentage of height (FR%-Height) was calculated. If the correlation between FR and FR%-Height was linear, the latter measure alone could be used in analyses as an indicator of dynamic balance control.

For Example:

	Functional Reaches				
Height	**1st**	**2nd**	**3rd**	**FR** i.e. (38 + 37 + 42) / 3	**FR%Height** i.e. (39/175.5) x 100
175.5 cm	38 cm	37 cm	42 cm	**39 cm**	**22.2%**

The participants were shown how to complete the SS-180, following the protocol outlined in Section 4.2. The researcher demonstrated the starting position and the target to which the participants were required to walk and ensured that they understood the protocol. The SS-180 was recorded using CODA and Video. Four CODA markers were attached to the shoes (one over each great toe and one on the midline of each heel) as shown in **Figure 5.1**.

Figure 5.1.
CODA Markers

The receiving unit was positioned approximately 3m behind the participants, in the position of the target to which they would walk. The camera was positioned on the CODA unit and set to record the participants throughout the turn. Recording was initiated before the participants were given their instructions, then ran continuously through the test. Sections I and II of the SS-180 were rated from the CODA data. The Starting Positions and size and direction of each of the Turning Steps were also measured from the CODA output (see below). Turn Quality Score was rated from the video record.

5.2.2 a Analysis

CODA Measurements: Starting Position and Turning Steps

The positions of the left and right heel markers in the starting position in the lateral (X) and AP (Y) planes were ascertained, allowing their separation to be calculated. Lateral Heel Separation was the distance between the markers in the frontal plane and Heel AP Difference was their difference in the saggittal plane (see **Figures 5.2 and 5.3**). The position of the markers in the X and Y dimensions after each turning-step was ascertained, allowing the width and length of each step to be calculated. The width was calculated by subtracting the new marker position in the frontal plane from the position of the ipsilateral heel marker in the frontal plane in the starting position. Increasingly negative values meant that the new marker position was further left than was the corresponding heel marker at the start.

The length of each turning step was calculated by subtracting the new marker position in the saggittal plane from the position of the ipsilateral heel marker in the saggittal plane at the start. Increasingly negative values implied that the new marker position was nearer the target than was the corresponding heel marker at the start. So that the participants of different heights could be compared meaningfully, the values attained (in cm) were all transformed into a percentage of body height.

As described in relation to external validity in Section 4.3, Turn Type was determined by the parameters (size and direction) of Turning Steps One and Two. The Turn Type selected was the one where the definition best matched the number and parameters of the turning-steps demonstrated. The length of the final turning-step determined how much progress the participant had made from the starting position toward the target while turning. When only two turning-steps were demonstrated, Turning Step Two was considered the Final Turning Step. The time at which the first Turning Step commenced and the time at which the final Turning Step was completed were ascertained: the difference was considered the Turn Time.

Figure 5.2. Example CODA Output Graph showing Starting Position and Marker Movement in the Lateral Plane (i.e. step width)

The separation between the heel markers (shown by the vertical double-headed arrow) was 15.3cm in the Starting Position (⇓). The X-axis represents time and the thick blue arrow (⇓) marks the onset of the first Turning Step: the left heel marker moved right, toward then beyond the right heel marker. NB. The line labelled 'Bottom' indicates the point of application of force through the force plate on which the subject was standing in the starting position. This data was recorded along with the 3D motion analysis but not analysed further in this thesis because of the limitations of using only one CODA recording unit (as discussed in **Section 5.4.2**).

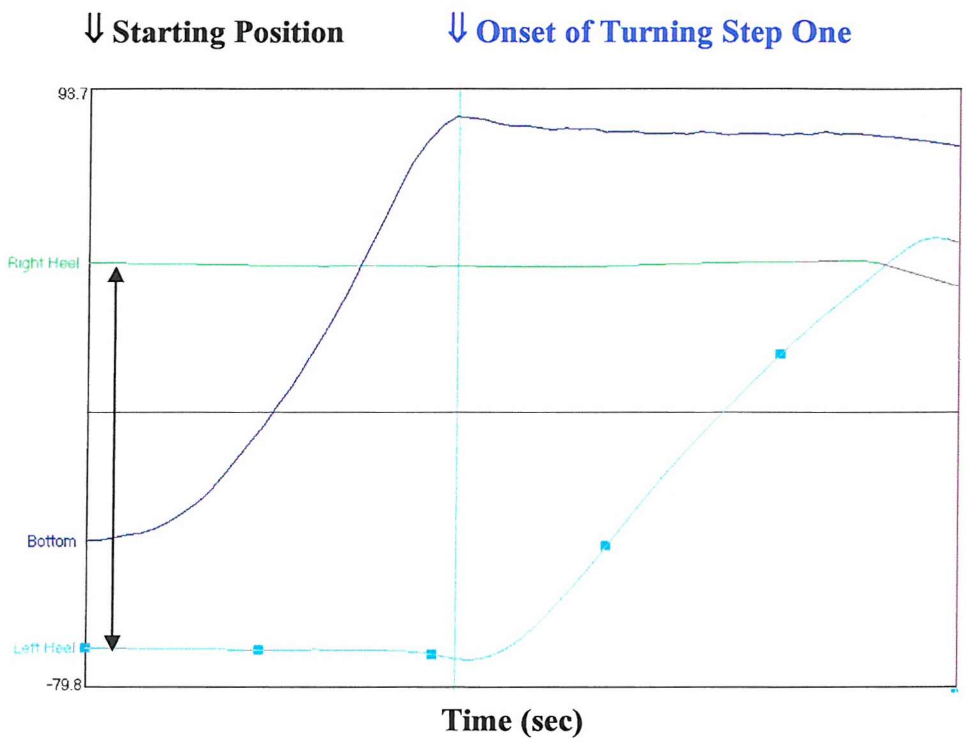
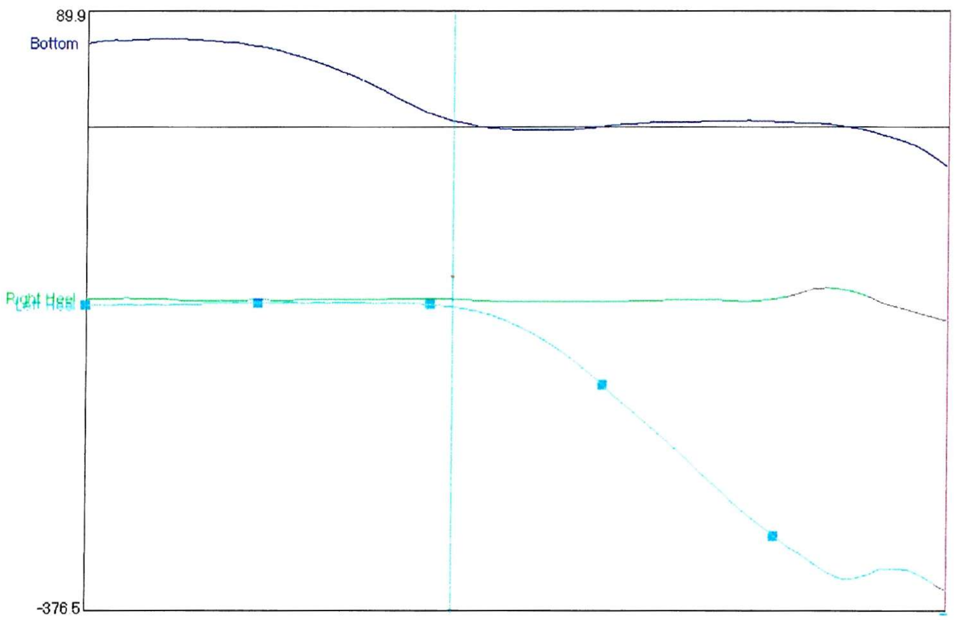


Figure 5.3. Example CODA Output Graph showing Step Size and Marker Movement in the Frontal Plane (i.e. step length)

The difference between the heel markers was 1.6cm in the Starting Position. The X-axis represents time and the thick blue arrow (⇓) marks the onset of the first Turning Step: the left heel marker moved backward, toward the target. NB. As in **Figure 5.2,** the line labelled 'Bottom' indicates the point of application of force through the force plate on which the subject was standing in the starting position.

⇓ Starting Position **⇓ Onset of Turning Step One**



Time (sec)

Video

Turn Quality Score was assessed from the video record. The five constituent items were scored in keeping with the protocol outlined in Section 4.2.4. Scores for the DU and DS Turns and Mean Turn Quality Scores (minimum 0, maximum 5) were then calculated.

Data Analysis

Sample Characteristics

The independent sample t-test was used to compare the ages of the men and women recruited. The correlation between FR and height-adjusted FR was assessed using the correlation coefficient.

How Healthy Adults Turned

Paired sample t-tests were used to compare a) the starting positions adopted by the participants before the DU and DS Turns (i.e. heel separation), b) the times taken to complete both turns and c) the progress made towards the target during both turns. The non-parametric Wilcoxon Signed Ranks Test was used to compare the number of steps taken to complete both turns. The correlations between the times and steps taken during both turns were assessed using the correlation coefficient. The association between maintaining the same Turn Type (from the DU Turn to the DS Turn) and maintaining the same movement-initiating foot was assessed using Fisher's Exact Test, as was the association between gender and the maintenance of Turn Type. The independent sample t-test was used to compare the age, balance control and performances on Section I of the SS-180 of those who maintained Turn Type and those who changed.

Parameters of the Turn Types

Descriptive summaries of the Turn Time and Turning Steps taken to complete each Turn Type are presented. The magnitude of the first, second and final Turning Steps taken during each Turn Type are summarised with medians and inter-quartile ranges. Values are given firstly for the lateral movement of each Turning Step, i.e. the change in the marker position in the frontal plane from the starting position to the position at the end of the Turning Step.

Values are then given for the A-P movement of each Turning Step, i.e. the movement of the marker toward the target from the starting position to the end of the Turning Step: negative values indicate a decrease in the gap between the starting position and the target. The Kruskal-Wallis Test was used to identify differences in a) the Times taken to complete each Turn Type and b) the progress made to the target during each Turn Type.

Correlates of Turning

Chi-square (or Fisher's Exact Test, *FET*) was used to measure the strength of the associations between the variables Hand Dominance, Direction of Turning, Movement-initiating Foot, Gender and Turn Type. Differences in the distribution of the continuous variables Turning Steps, Turn Time, Progress to the Target, Balance Control and Age were tested with T-Tests, Kruskal-Wallis Tests or Mann-Whitney Tests, as appropriate.

5.3 Results

5.3.1 The Sample

Thirty-three participants were recruited (age range 21 - 83); 13 men and 20 women (**Table 5.1**). The men and women were of similar age (t-test, $t = 0.51$, P = 0.613). Mean height was 171.1cm (± 7.7) and mean FR was 33.0cm (± 5.5).

Table 5.1. Sample Characteristics (n = 33 Healthy Adults)

Variable	Value	Total Sample	*Men*	*Women*
Sex	M : F	13 : 20 (39% : 61%)		
Age (Years)	Mean (SD)	42.2 (13.7)	*43.8 (17.2)*	*41.3 (11.3)*
	Median (IQR)	40 (32 – 52)	*37.0*	*42.0*
FR%Height	Mean (SD)	19.3% (3.0)	*19.6% (2.4)*	*19.1% (3.3)*
	Median (IQR)	19.2% (17.3% – 21.6%)	*19.9%*	*19.2%*

The men were slightly taller than were the women (175.7cm (± 8.8) *v* 168.1cm (± 5.3)) and had a slightly longer reach (34.4cm (± 4.7) *v* 32.1cm (± 5.9)).

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FR and FR%Height were very closely correlated (r = 0.967, P = 0.000, **Appendix 4**): from this point forward, 'Balance Control' will be taken to refer to the latter. In this sample, as age increased, balance control tended to decrease (r = -0.557, P = 0.001). Balance control was similar in the men and women (*t = 0.458*, P = 0.650).

5.3.2 How Healthy Adults Turned

The participants adopted similar starting positions before the DU Turns and DS Turns (**Table 5.2**). The median separation between the heels was less than 8% of body height and the median A-P difference was less than 1% in both conditions.

Table 5.2. Starting Position for the SS-180 (n = 31)

Variable	**Value**	**DU Turn**	**DS Turn**	
Heel Separation (% of height)	Mean (SD) Median (IQR)	7.8 (2.7) 7.6 (6.2 – 9.4)	7.5 (2.1) 7.5 (5.6 – 9.1)	t = 1.013, P = 0.319
Heel A-P Difference (% of height)	Mean (SD) Median (IQR)	1.2 (1.6) 0.9 (0.6 – 1.2)	1.1 (1.9) 0.7 (0.2 – 1.1)	t = 0.852, P = 0.401

The DU Turns and DS Turns demonstrated were completed taking a similar number of steps (*z = -1.000,* P = 0.317), in similar times (*t = -1.102,* P = 0.279; **Table 5.3**).

Table 5.3. SS-180 Section 1: Time and Steps (n = 31)

Variable	**Value**	**DU Turn**	**DS Turn**	**Mean: (DU + DS) / 2**
Turning Steps	Mean (SD) Median (IQR)	2.5 (0.6) 2 (2 - 3)	2.5 (0.6) 3 (2 – 3)	2.5 (0.5) 2.5 (2 - 3)
Turn Time	Mean (SD) Median (IQR)	1.6 (0.4) 1.5 (1.3 – 1.7)	1.6 (0.5) 1.6 (1.3 – 1.9)	1.6 (0.4) 1.5 (1.4 – 1.8)

Times taken to complete the DU and DS Turns were closely correlated (r = 0.628) as were the numbers of steps (r = 0.595), see **Appendix 5**. Seventy percent of the participants (21/30) advanced further to the target during the DS Turn than during the DU turn (mean DS advance 56.9% (15.9) *v* mean DU advance 51.5% (21.9); *t=1.717*, P=0.097).

Toward Turns were the Type demonstrated most commonly; Incremental Turns were rare (4.8%), see **Table 5.4**.

Table 5.4. SS-180 Section II: Turn Types (n = 31)

Turn Type	DU Turn	DS Turn	All Turns
Incremental	02 (06.5%)	01 (03.0%)	03 (04.8%)
Pivotal	07 (22.6%)	13 (41.9%)	20 (32.5%)
Towards	12 (38.7%)	10 (32.3%)	22 (35.5%)
Lateral	10 (32.3%)	07 (22.6%)	17 (27.4%)

Twenty-one participants (67.7%) demonstrated the same Turn Type under both conditions while others changed Type from the DU Turn to the DS Turn (**red in Table 5.5**); 67.7% changed their movement-initiating foot.

Table 5.5. DU Turn Types by DS Turn Types (n = 31)

		DS Turn Type				
		Incremental	Pivotal	Toward	Lateral	Total
DU Turn Type	Incremental	1	-	-	**1**	02
	Pivotal	-	7	-	-	07
	Toward	-	**3**	8	**1**	12
	Lateral	-	**3**	**2**	5	10
	Total	01	13	10	07	31

Those who persisted with the same movement-initiating foot were more likely to change turn type (FET; P = 0.004, **Table 5.6**).

Table 5.6. Consistency in Turn Type by Consistency in Movement-initiating Foot

		Movement-initiating Foot Consistency		
		Same Foot	Changed Foot	Total
Turn Type Consistency	Same Type	3	18	21
	Changed Type	7	3	10
	Total	10	21	31

Those who maintained and changed Turn Type had performed their DU Turns similarly (**Table 5.7:** Steps P = 0.771, Time P = 0.276) and went on to perform the DS Turns in similar ways (Steps P = 0.313, Time P = 0.142). The *mean* number of steps and time taken to turn was also very similar in the group who changed Turn Type and the group who maintained it (Steps P = 0.480, Time P = 0.150).

Table 5.7. Consistency in Turn Type: Turning Steps and Turn Time (n = 31)

			Maintained Turn Type (n = 21)	Changed Turn Type (n = 10)
DU Turn				
	Steps	Mean (SD)	2.4 (0.6)	2.5 (0.7)
	Time (s)	Mean (SD)	1.5 (0.3)	1.7 (0.5)
DS Turn				
	Steps	Mean (SD)	2.5 (0.6)	2.7 (0.5)
	Time (s)	Mean (SD)	1.5 (0.5)	1.8 (0.4)
Mean				
	Steps	Mean (SD)	2.5 (0.6)	2.6 (0.5)
	Time (s)	Mean (SD)	1.5 (0.4)	1.7 (0.4)

Turn Quality Scores were very consistent. The participants all successfully turned in both directions, none demonstrated any impairment in stability, posture or ground clearance. Only one participant paused after turning before commencing straight-line gait, one of the participants who demonstrated an Incremental Turn. Turn Quality Scores were not suitable for any further analysis because of their distribution.

5.3.3 Parameters of the Turn Types

Table 5.8 outlines the parameters of the four Turn Types that were demonstrated by the sample. Visual representations of Turn Types are presented in **Appendix 1**.

Table 5.8: Turn Type Frequency, Turning Steps and Turn Times.

Type	Turns	Participants	Time (s) Median (IQR)	Steps
Toward	22 / 62 (35%)	14 / 31 (45%)	1.4 (1.3 - 1.6)	2
Pivotal	20 / 62 (32%)	13 / 31 (42%)	1.7 (1.2 - 1.9)	2 or 3
Lateral	17 / 62 (27%)	12 / 31 (39%)	1.7 (1.4 - 1.8)	2 or 3
Incremental	03 / 62 (5%)	02 / 31 (7%)	2.9	4

Turn Times

Toward Turns were the Type completed fastest of all (taking a median 1.4 seconds) and Incremental Turns were slowest. The Kruskal-Wallis Test did not reveal a significant difference in either the DU Turn Times ($P = 0.136$) or the DS Turn Times ($P = 0.266$).

Turning Steps

Toward Turns were all initiated with the inside foot and Pivotal Turns were initiated with the inside foot in 90% of cases, whereas the Lateral Turns were all initiated with the outside foot. The Incremental Turns were initiated with either foot. Toward Turns were all completed in two Turning Steps. Pivotal Turns were completed in two or three Turning Steps (the majority, 60%, took three), as were Lateral Turns (the majority, 76.5%, took three). Incremental Turns were all completed in four Turning Steps.

Foot Placement during Turning

In **Table 5.9** the width and length of the Turning Steps are summarised.

Table 5.9: The Magnitude of the Turning Steps by Turn Type

	Turning Step					
	1st		2nd		Final	
Type	**Lateral**	**A-P**	**Lateral**	**A-P**	**Lateral**	**A-P**
Toward	4 (2 – 7)	-21 (-13 - -28)	14 (10 – 18)	-64 (-55 - -74)	*As 2nd Step*	
Pivotal	11 (5 – 19)	3 (-4 – 9)	33 (17 – 41)	-26 (-9 - -50)	18 (13 – 24)	-56 (-44 - -65)
Lateral	5 (2 – 9)	2 (1- 13)	5 (2 – 14)	-17 (9 - -27)	12 (9 – 17)	-41 (-32 - -64)
Incremental	5	1	4	5	1	-33

Figures are medians (with IQR).

In Toward Turns, both Steps were much longer than they were wide, each moving the participant nearer the target. In Pivotal Turns, the first Step was wider than it was long, wider than the first Step of any other Turn Type. The second Step was even wider, moving the participant approximately one third of their height laterally and a similar distance towards the target. In Lateral Turns, the first Step was small, a lateral repositioning of the outside heel that broadened the base slightly. The second Step was longer than it was wide and after two Steps, the participants were approximately 17% of their height towards the target. In the Incremental Turns, the first steps were small, the participants making negligible progress towards the target. The participants made progress away from the target with the first two Steps. There was a significant difference between Turn Types in the advance made toward the target during the first Turning Steps of the DU Turns (P = 0.000) and the DS Turns (P = 0.000).

Onset of Straight Forward Gait (i.e. advance to target while turning)

Straight forward gait toward the target commenced at a distance equivalent to approximately two thirds of body height away from the starting position after a Toward Turn: participants moved nearer the target in this Turn Type than in any other. After a Pivotal Turn, the participants commenced straight forward gait at approximately 60% of their height away from the starting position. After a Lateral Turn, the participants commenced straight forward gait at a distance of less than half of their height away from the starting position. After Incremental Turns, the participants commenced straight forward gait when they were still at the starting position, although they had turned to face the target. There was a difference nearing significance between Turn Types in the advance made toward the target while performing a DU Turn (P = 0.070). Progress made during the DS Turns was similar across the Turn Types (P = 0.286).

5.3.4 Correlates of Turning

Hand Dominance

Twenty-one participants (68%) turned first toward their dominant hand (*FET, P = 0.272*). Dominance was not associated with the first foot moved: in the DU Turn, 18 participants (58%) first moved the foot on their dominant side (*FET, P = 0.333*) and, in the DS Turn, 12 participants (39%) first moved the foot on their dominant side (*FET, P = 0.101*).

Gender

The 12 men and 19 women demonstrated similar numbers of steps and took similar times to complete the DU Turns and DS Turns (**Table 5.10**). Mean Turning Steps (*t = 0.341, P = 0.735*) and Turn Times *(t = 1.182, P = 0.247*) were also similar for men and women.

Table 5.10: Gender, Turning Steps and Turn Time (n = 31)

		DU Turn		DS Turn		Mean	
		Men	**Women**	**Men**	**Women**	**Men**	**Women**
Steps	Mean (SD)	2.5 (0.7)	2.4 (0.6)	2.6 (0.7)	2.5 (0.5)	2.5 (0.6)	2.5 (0.5)
Time (s)	Mean (SD)	1.6 (0.3)	1.5 (0.5)	1.8 (0.6)	1.5 (0.4)	1.7 (0.4)	1.5 (0.4)

In the DU condition, men and women demonstrated a similar distribution of Turn Types (*Chi-Square, P = 0.665*). The distributions differed in the DS condition, although the association between gender and Turn Type just missed statistical significance (*Chi-Square P = 0.064*), see **Table 5.11**. A similar proportion of men and women changed Turn Type for the DS Turn (*40% v 32%; FET,* P = 1.000). Men and women made similar progress toward the target when turning, both in the DU Turn (*mw –1.014;* P = 0.311) and in the DS Turn (*mw –0.339;* P = 0.735).

Table 5.11: Gender and Turn Type (n = 31)

		DU Turn		DS Turn	
		Men	Women	Men	Women
Turn Type	Incremental	1 (08.3%)	1 (05.3%)	1 (08.3%)	0
	Pivotal	4 (33.3%)	3 (15.8%)	7 (58.3%)	6 (31.6%)
	Toward	4 (33.3%)	8 (42.1%)	4 (33.3%)	6 (31.6%)
	Lateral	3 (25.0%)	7 (36.8%)	0	7 (36.8%)

Balance Control

As shown in **Table 5.12**, balance control was correlated with the number of steps and time taken in the DU and DS Turns and with the mean number of steps and time taken.

Table 5.12: Correlation between Balance and Section I of the SS-180 (n = 31)

		DU Turn		DS Turn		Mean	
		Time	**Steps**	**Time**	**Steps**	**Time**	**Steps**
FR% Height	r	**-0.478**	**-0.523**	**-0.488**	**-0.426**	**-0.535**	**-0.534**
	P	0.007	0.003	0.005	0.017	0.002	0.002

The participants who demonstrated different DU Turn Types demonstrated similar levels of balance control (*kw 5.509,* P = 0.138, **Table 5.13**). However, there was a difference in the balance control of those demonstrating different DS Turn Types (*kw 7.879,* P = 0.049). The 21 participants who maintained Turn Type demonstrated similar balance control (19.7% ± 3.0) to the 10 who changed Type (19.0 ± 2.9); *t = 0.557*, P = 0.582.

Table 5.13: Balance Control and Turn Type

			Turn Types			
			Incremental	**Pivotal**	**Toward**	**Lateral**
DU Turn	**FR% Height**	Mean (SD)	15.7 (1.6)	20.6 (2.3)	20.1 (2.7)	18.6 (3.3)
		Median	15.7	21.4	20.2	18.6
		Range	15 - 17	17 - 23	15 - 26	13 - 24
DS Turn	**FR% Height**	Mean (SD)	16.8 *	20.7 (2.1)	20.0 (2.6)	16.7 (3.3)
		Median		20.1	20.2	15.3
		Range		17 - 24	16 - 26	13 - 22

* n = 1

As balance control improved, more progress was made during the first two Turning Steps in both the DU Turn (r = 0.404; P = 0.024) and the DS Turn (r = 0.424; P = 0.017).

Age

As shown in **Table 5.14**, age correlated with the number of steps and time taken during the SS-180, with the exception of DU Turn Time.

Table 5.14. Correlation between Age and Section I of the SS-180 (n = 31)

		DU Turn		**DS Turn**		**Mean**	
		Time	**Steps**	**Time**	**Steps**	**Time**	**Steps**
Age	r	0.187	**0.445**	**0.598**	**0.502**	**0.457**	**0.529**
	P	0.314	0.012	0.000	0.004	0.010	0.002

Participants who demonstrated different DU Turn Types were of similar ages (*kw 5.664,* P = 0.129) but there was a difference in the ages of those demonstrating different DS Turn Types (*kw 8.506,* P = 0.037); **Table 5.15**. Those who maintained Type were of similar age (42.3 ± 14.5) to those who changed Type (38.5 ± 10.2); *t= 0.740*, P = 0.465.

Table 5.15: Age and Turn Type

			Turn Types			
			Incremental	**Pivotal**	**Toward**	**Lateral**
DU Turn	**Age**	Mean (SD)	62 (29.7)	36.6 (11.5)	36.7 (10.1)	45.3 (10.6)
		Median	62	35	37	46.5
		Range	41-83	21 - 59	21 - 52	30 - 62
DS Turn	**Age**	Mean (SD)	83 *	35.2 (9.9)	39.2 (9.4)	48.6 (10.3)
		Median		35	39	52
		Range		21 - 59	27 - 54	30 - 62

* n = 1

As age decreased, more progress was made during the first two Turning Steps in both the DU Turn (r = 0.371; P = 0.040) and the DS Turn (r = 0.442; P = 0.013).

The sample median age was 40. The 16 participants under 40 had a median age of 32; the 15 aged 40 years or older had a median age of 52. The younger half had better balance (a longer height-adjusted FR than the older half of the sample (medians 21% *v* 19%). The groups of younger and older adults performed their DU Turns in similar ways (**Table 5.16**), although the differences in Turn Types and Turning Steps neared statistical significance. In the DS Condition, the younger group turned faster than the older group did, using different Turn Types. In the Young Group, those with better balance (a longer height-adjusted FR) turned faster under both DU and DS Conditions (r = -0.63, P = 0.009 and r = -0.70, P = 0.002, respectively) and advanced further during a DS Turn (r = 0.59, P = 0.043) than those with worse balance. In the Older Group, those with better balance took fewer steps during a DU Turn (r = -0.60, P 0.019) than those whose balance was not so good.

Table 5.16: Turns demonstrated by adults under and over 40 years of age (n = 31)

			Adults under 40 (n=16)	Adults 40+ (n =15)	P Value
DU Turn	**Steps**	Med	2	3	0.080
	Time (s)	Med	1.4	1.6	0.157
	Turn Type				
	Incremental		0	02 (13)	0.058
	Pivotal		06 (38)	01 (07)	
	Toward		07 (44)	05 (33)	
	Lateral		03 (19)	07 (47)	
	Progress	Med	-54%	-63%	0.948
DS Turn	**Steps**	Med	2	3	0.088
	Time (s)	Med	1.5	1.8	0.010
	Turn Type				
	Incremental		0	01 (07)	0.040
	Pivotal		10 (63)	03 (20)	
	Toward		05 (31)	05 (33)	
	Lateral		01 (06)	06 (40)	
	Progress	Med	-58%	-57%	0.963

5.3.5 Summary of Findings

A convenience sample of 33 healthy adults, median age 40 years, was studied. The ages and levels of balance control of the 13 men and 20 women studied were similar.

<u>How Healthy Adults Turned</u>

The sample adopted similar Starting Positions before the DU and DS Turns. The steps and times taken to complete both turns correlated closely. Most participants turned in three steps or fewer (mean 2.5, ± 0.5), taking no longer than two seconds to do so (mean 1.6s, ± 0.4s).

Toward, Pivotal and Lateral Turns were common. Incremental Turns were rare among this sample. Two-thirds of participants demonstrated the same Turn Type under both conditions and two-thirds changed their movement-initiating foot. Those who maintained Type were more likely than were those who changed to change their movement-initiating foot.

With the exception of one participant, the sample scored 5 / 5 for Turn Quality on every turn. That is, during standing-start turns these healthy adults were independent and stable, maintained their posture, cleared the floor with both feet and moved continuously throughout the turn into straight forward gait.

As they turned, participants advanced toward the target a distance of slightly over half their height, before they commenced straight forward gait (e.g. DU mean advance 51.5% ± 21.9%). There was a tendency for participants to advance further during the second turn (the DS Turn) than during the first (P = 0.097).

Turn Type Parameters

Incremental Turns were the Type completed slowest by this sample and required four Turning Steps: after the initial Turning Step with each foot, negligible advance toward the target had been made (equivalent to just 5% of participant height).

Pivotal Turns were completed in two or three Turning Steps, the first of which was taken with the inside foot in 90% of cases: there was more lateral movement associated with this Turn Type than with any other.

Towards Turns were completed fastest by this sample and only required two long, narrow Turning Steps, the first of which was taken with the inside foot: participant's advanced a distance of approximately two-thirds of their height towards the target as they turned.

Lateral Turns were completed in two or three Turning Steps, the first of which was a small lateral movement taken with the outside foot, widening the base.

Correlates of Turning

Hand dominance was not associated with the direction chosen in which to turn, or with the selected movement-initiating foot.

Men and women took similar Steps and Times and advanced similar distances while turning; similar proportions changed Turn Types from the DU to the DS Turn. Men and women tended to demonstrate different Turn Types when direction was specified ($P = 0.064$).

Balance control and age correlated with Turning Steps and Turn Times and with the distance advanced after the first Turning Steps had been taken. The balance control and ages of the participants who demonstrated different Turn Types in the DS Turn differed.

The younger and older halves of the sample tended to take different numbers of Turning Steps ($P = 0.080$) and demonstrate different Turn Types ($P = 0.058$) in the DU condition. When direction was specified, the younger half turned faster than the older half, using different Turn Types, and tended to take fewer Turning Steps ($P = 0.088$).

5.4 Discussion

This study was designed to yield information about the strategies demonstrated by healthy adults during the newly developed Standing-start 180° Turn Test. Earlier in this thesis, the relative lack of research into turning was highlighted. The findings from this investigation have contributed to filling the gap in our understanding of what has been described as an 'integral part of functional locomotion' (Morris et al, 2001). Conducting the first investigation using the SS-180 with a sample of healthy adults, under laboratory conditions, was useful for three reasons. Firstly, a picture began to emerge of what constituted a 'normal' turn from a standing-start. The findings provided the first data set on the performance of a test intended to identify dysfunctional turning; if this study had not been completed, it would be difficult to interpret the performance of the SS-180 by people with PD, or any other condition associated with dysfunctional turning.

Secondly, the physical environment was controlled and constant. Emergent differences between individuals need not be attributed to differences in the data collection situation. Thirdly, measurement tools not available outside the laboratory setting made it possible to record turning accurately and to externally validate the video rating against a 'gold standard' at the same time (see Section 4.3).

The discussion that follows centres on the findings of the study and the issues that have arisen from conducting the new test and analysing the data. It is not possible to compare the findings directly with those of any other study, as a standing-start protocol has not been reported before. The sample recruited included men and women with a range of ages spanning more than 60 years. In comparison with the earlier laboratory-based investigations outlined in Section 3.4, the sample was intended to be considerably larger (n = 33) and the mean age considerably higher (42.2 ± 13.7).

5.4.1 How Healthy Adults Turned

The step count is one of the aspects of turning that has been most widely reported. In this study, standing-start turns were completed in a mean 2.5 Turning Steps (± 0.5). It is difficult to compare this finding with those of researchers who have studied different types of 180° turn and defined turning steps in different ways, for example Thigpen et al (2000) and Simpson et al (2002). The former counted a mean 1.3 (± 0.4) steps during walking 180° turns and the latter counted a mean 6.4 (± 3.9) steps during stationary 180° turns. The age structures of their samples were quite different and different also to that of the sample described here. It may be that a standing start-turn lies on a continuum between walking and stationary turns, in terms of the number of turning steps demanded by the task. The standing-start turn was accomplished very efficiently. Turning 180° in just two or three steps means that each step brought about a 60° to 90° change in orientation of the body and it seems likely that a high degree of 'trunk control' was being exercised during these long swing phases, as suggested by Morris et al (2001).

In this study, turning was completed in a mean 1.6s (± 0.4). This timing does not take into account the elements of planning and preparation that may precede movement. When rating turning from video, it was essential to choose a clearly distinguishable activity (i.e. the first foot repositioning observed) as the stimulus to begin timing.

In this respect, timing from a standing-start is easier than timing a walking 180° turn because the need to decide whether a step was the first turning step or not was negated. Again, the speed with which it was accomplished suggests that, to the healthy adults recruited, the turn was an easily accomplished component of the SS-180. The Turn Times measured were similar to those measured by other researchers, though once again difficult to compare directly due to procedural differences. As far as it is possible to comment, however, the findings were not unlike those of Thigpen et al (2000), who reported a mean *walking 180° turn time* of 1.4s (± 0.3) in young adults and 2.1s (± 0.7) in elderly adults. Imms and Edholm (1981) reported a longer turn time in their elderly participants (4.0s ± 1.3), a difference that may be explained by either the sample studied and/ or the measurement technique, particularly the start and end points of turning.

Most other researchers who have measured Turning Steps and Turn Time have not measured other aspects of turning that may be related. In this investigation it was intended to explore the relationships between Steps and Time and *Turn Type* and *Turn Quality Score*. Turn Quality Score, however, was so consistent across the sample that further analysis was inappropriate. The finding that, with one exception, all 66 turns demonstrated were rated five out of five raises the proposition that the SS-180 is not challenging to a healthy adult. The Turn Types differed in the times and number of steps taken to complete them but one can only speculate as to whether the selection of Turn Type dictates the number of steps and time taken, or *vice versa*. The differences, although statistically significant, were small.

Of all the components of the SS-180, Turn Type was the one that revealed most variation among healthy people. Toward, Pivotal and Lateral Turn Types were common and one concludes that all three can be considered 'normal'. Turn Type is a difficult variable to compare across studies as different researchers have used different definitions. Some comparison is possible with the work of Ashburn and Stack (1999) and Thigpen et al (2000), both of who rated the turns demonstrated during the 'Timed Up and Go' Test and with the work of Hase and Stein (1999), who also studied walking 180° turns. In work completed prior to this thesis, Ashburn and Stack observed that healthy adults only demonstrated turns defined as 'Forward', 'Sideways' and 'Twisting' or combinations thereof (see Section 3.4.3 for the definitions).

These Turn Types were similar to the prevalent Types observed in the current study, characterised in general by constant and steady, goal-directed foot placement throughout. Thigpen et al described 'an early pivot approach' to turning as predominant in the young people who they observed and, in the current study, people in the younger half of the sample demonstrated 80% of the Pivotal turns observed. The Spin Turns and Step Turns described by Hase and Stein were not remarkably different to the Turn Types described in any of the other studies. Therefore, a trend is becoming apparent in the Turn Types used by healthy adults: at a simplistic level, healthy adults turn180° (be it from a walking or a standing start) by constantly stepping towards the goal or pivoting on a planted foot. For healthy adults, it may be that only a *standing-start* turn is challenging enough to necessitate an Incremental type turn, characterised by several, small steps 'on-the-spot': such a turn was rare in the current study but has not been reported *at all* in healthy adults performing walking 180° turns.

As four Turn Types were demonstrated during this study, one has to consider why individuals chose the one that they did. Patla et al (1991) first discussed the element of 'planning' a turn prior to its execution and based their ideas on the finding that a turn could not be instigated during a step that was underway. Later work (Patla et al, 1999) suggested that foot placement was the dominant mechanism underpinning 'steering' when time was available for advanced planning of the turn. A standing-start turn clearly had the potential for planning; movement was not demanded on a cue. The instructions given to the participants were intended to avoid them feeling compelled to move immediately, i.e. '*when you are ready*, please walk'. Hase and Stein (1999) concluded that the leg that was leading when the need to turn arose dictated the choice of Turn Type made during a walking turn. There was no such compunction during the SS-180, so the reason underlying the choice of Turn Type must lie elsewhere. Whereas Morris et al (2001) required their participants to step on a force plate whilst turning, the participants in the current study were not restricted in any way; their foot placement and hence Turn Type was an entirely free choice.

It may be that an individual's age and his or her ability to control dynamic balance are the two factors that most influence how a standing-start turn is accomplished. Both younger age and better balance were associated with faster turning and taking fewer steps.

The participants who demonstrated Pivotal and Toward Type Turns were younger and had a longer height-adjusted FR than the participants who demonstrated Lateral and Incremental Turns. Age and balance control were closely correlated in this sample: as such, the apparent relationship between either one of them and turning may, of course, be spurious. Height-adjusted FR showed a very close linear relationship with FR and will be used to measure balance in further studies. The findings that aspects of turning are associated with the turner's age and balance are in keeping with those of other researchers (Tinetti et al, 1986; Lipsitz et al, 1991; Shenkman et al, 1996; Cao et al, 1997; Thigpen et al, 2000; Simpson et al, 2002).

As the participants were all healthy adults with no history or complaint of difficulty turning, one must be cautious in suggesting that certain Turns demonstrated (i.e. Incremental and perhaps even Lateral Types) may have been in any way compensatory – but the possibility exists. The demands of a Toward or Pivotal Turn may be such that people who can not achieve the ranges of movement necessary, or the speed, strength or balance, develop other (less demanding) ways of turning. Clearly, from the current investigation, just what the 'demands' of a Toward or Pivotal Turn may be cannot be identified. However, other researchers have attributed differences in the ways individuals turn to age, strength, speed and balance (Cao et al, 1997; Thigpen et al, 2000). In the current study, the Turn Types demonstrated during the DS Turn came close to a significant difference in distribution between the sexes. Cao et al (1997) attributed the gender differences in turning that they demonstrated to differences in strength between men and women. Although the groups of men and women in the current study were small, it did not appear that gender played a part in determining how an individual turned: men and women performed during the SS-180 in very similar fashions.

The vast majority of the turns demonstrated combined the rotational element (by which the turner came to face the target) with an element of translation (whereby the turner moved nearer to the target): only three were 'Incremental' and, by definition, 'on-the-spot'. That is, healthy adults completed the SS-180 without having to break down the task into two distinct phases, rotation followed by translation. Hase and Stein (1999) described successful walking turns as being so smooth that walking continued with little or no change in timing. The findings of the current study suggest that successful turns from a standing-start are similarly 'smooth' with the rotational element completed at the same time as the turner travels towards his or her target, not before.

Better balance was associated with travelling further toward the target while taking the initial Turning Steps. Perhaps only individuals with a high degree of balance control can adopt the long, narrow base area seen in a Toward Turn or stay balanced over one pivoting foot long enough to take a large Turning Step.

One feature of the results was the consistency with which healthy adults a) performed the SS-180 and b) turned in both directions. The ranges of values measured for both Turning Step Count and Turn Time were small, as reflected by their standard deviations and three Turn Types were demonstrated by at least a quarter of the participants. The Turn Quality Scores were all maximal except for one participant's turn (rated as four out of five). In the study by Simpson et al (2002), 81% of the participants took the same number of steps (plus or minus one) to turn in each direction: in the current study, every participant showed this consistency. This finding leads one to speculate that one could abbreviate the analysis to an indication of whether or not the DU and DS Turns were the same (or at least very similar). As this seems to be the case for the healthy adults studied so far, perhaps 'asymmetry' in turning could be an indicator of 'abnormality'.

The DU and DS Turns were performed in very similar ways but, interestingly, several participants commented that the two turns *felt* very different to them. Approximately a third of the participants changed Turn Type from the DU to the DS Turn. The two Turn Types that brought the turner nearest to the target (i.e. Toward and Pivotal) accounted for a greater proportion of the DS than DU Turns; this might explain why there was a difference nearing significance in the mean progress to the target between the DU and DS turns. It is interesting to consider why some people changed Turn Type from one turn to the next. There could be anatomical or physiological reasons why an individual has to adapt the way that he or she turns when turning in the direction other than the one that they would choose to turn. For example, asymmetrically restricted rotation in the trunk might necessitate different movements when turning in each direction; a strength deficit in one lower limb might necessitate using alternative turning strategies dependent on direction. Alternatively, we may develop a motor program for turning that tends to begin with a step by one preferred foot. Certainly, the participants who maintained the same movement-initiating foot tended to change Turn Type.

5.4.2 Conducting and Analysing the SS-180

The test protocol worked well, in that the participants carried out the instructions in the intended manner, i.e. when asked to do so, everyone walked from the starting position to the target. Only one participant turned 'on-the-spot' and paused before commencing straight forward gait. While it is possible that she needed to separate turning from straight forward gait, it seems unlikely, as her DS Turn merged *continuously* into gait. Therefore, it may have been that, in one case, the requirements of the test were not fully understood. It is also possible that the new protocol appeared to work so successfully because of the nature of the sample. The participants were not representative of a cross-section of society: rather, many of them were likely to be familiar with research (to a greater or lesser extent), able to grasp new instructions quickly and willing to comply with what was asked of them. To be confident that the test is workable, different samples would have to be tested by different researchers.

In designing the SS-180, and in particular in wording the instructions to the participant, the intention was to focus attention on walking to a target rather than on turning round to do so. It would be easy to ensure that participants always knew that they were expected to turn as they walked, rather than before, if the instructions were made more explicit. But, in light of the finding that the vast majority, if not all, of the participants tested so far did what was expected of them, there appears little reason to modify the wording of the instructions and risk focussing too much attention on turning.

The space that was available in which to conduct the SS-180 in the laboratory must be considered. The test is a mobility test, in the same way that the 10m walking test is, for example. Originality lies in a) the participants having to turn to face the target before walking toward it and b) the evaluation focusing entirely on the rotational component of the task, prior to straight forward gait. To encourage the participants to perform a standing-start turn rather than a stationary turn ('on-the-spot'); they were required to cover a distance of approximately 3m straight forward before reaching the target. The implication for testing outside the laboratory is that sufficient space must be available to encourage walking, i.e. the participant must be allowed to 'get into his or her stride'.

No safety issues arose when the new test was used. In this sample, there were no adverse incidents to report: no one fell or appeared likely to fall and no one reported anxiety about the test, or any pain or fatigue during its completion.

The time required analysing the SS-180 highlighted that the test would require simplification before it was appropriate for use in routine clinical practice. The parameters of both turns were very closely correlated so some parameters might usefully be dropped from the analysis in future. There was one technical limitation of using CODA to record the marker positions, though this could be overcome in future. The output graphs generated by CODA showed only the heel markers in the starting position, as the toe markers were blocked from the field of view by the participants' feet. It was the heel markers then from which the length and width of each turning-step was calculated. When interpreting the CODA output graphs, the toe markers came into the display as the turn was completed and the heel markers were lost from view, blocked by the participants feet: the time interval when neither marker was visible was very short. On the positive side, the onset of straight forward gait was clear on the CODA output graphs, so it was easy to delineate the turn.

This initial study could usefully be expanded, preferably using two CODA units in combination to capture foot placement in a 360° field of view: studying a greater number of healthy participants would strengthen the inferences that can be drawn. While even a large cross-sectional study could not show how turning changes with age, it could provide more accurate age-specific norms. To try to understand more about the different Turn Types and their performance, it would be useful to measure muscle activity and joint ranges (particularly around the trunk and hips) as the test was completed.

5.5 Conclusion

In the introductory chapter (Section 2.4), I hypothesised that turning was a highly balance-demanding activity. Here, evidence has emerged that the way a healthy adult turns from a standing-start is related to his or her level of dynamic balance control (i.e. height-adjusted FR). People with better balance control tend to take fewer turning steps, turn more quickly and advance further to their target than people who have a shorter height-adjusted functional reach; furthermore, they demonstrate different Turn Types. People of different ages also turn differently. Healthy adults perform the rotational component of the SS-180 while simultaneously making a translation toward the target. Common sequences of foot placement during standing-start turns have been identified: an initial movement of the foot ipsilateral to the direction of turning was most common, with only two or three steps required to orientate the turner toward the target and lead into straight forward gait.

In the following chapters, a similar study involving a small sample of people with PD will be described, then a larger study involving people with and without PD that was conducted in the participants' homes. The findings of this investigation will be considered again, in the light of the findings from the other studies, in Chapter Nine. The differences in the way people with and without PD turn will be identified and possible explanations discussed.

Chapter Six

A Preliminary, Laboratory-based, Investigation of how People with PD perform the Standing-start 180° Turn Test

6.1 Introduction

In this chapter, a small laboratory-based investigation (the first study in which the SS-180 was used with people with PD) is reported and discussed. The study was intended to precede a larger study conducted in people's own homes. To minimise unnecessary repetition in describing the procedures and tools used in this investigation, reference will be made to the study described in the previous chapter, which will be referred to from this point on as the *Healthy Adult Study*.

Previous experience working with people with PD suggested that laboratory-based investigations were limited in a number of ways:

1. People with PD were reluctant to travel to the laboratory.
2. The sample was often at the milder end of the spectrum, and
3. Performance was likely to be affected by the context.

There were, however, three reasons why this small, laboratory-based investigation was undertaken: 1) to validate the video-analysis, 2) to highlight any hazards in conducting the newly developed SS-180 and 3) to acquire an understanding of how people with PD performed the test. The SS-180 was developed for analysis from video, so that it could be used in both clinical and domestic settings. The current study provided the opportunity to use laboratory-based motion-analysis tools in addition to the video camera for two reasons:

1) To externally validate the video analysis against a 'gold standard' (see Chapter Four), and
2) To measure aspects of turning not possible from the video record (e.g. *Heel Separation* prior to turning and the magnitude of *Turning Steps*).

Before this study was undertaken, the SS-180 had not been used with anyone other than healthy adults; its suitability for use with people who were potentially seriously disabled by PD (and therefore likely to experience marked postural instability) had not been tested.

For safety reasons, it was desirable to trial the newly developed test in a safe environment before taking it into people's homes where the researcher would be working single-handedly. As turning is known to be one of the most common causes of falls among people with PD, a test in which turning was an integral part had the potential to seriously challenge the participant's postural stability. In the laboratory, colleagues could have assisted should any adverse events (such as falls) have occurred.

This preliminary study was intended to highlight some of the ways in which the standing-start turns of people with PD differed from those of the healthy adults studied earlier (Chapter Five). This was the least important objective: the study would be small and a further study was planned to include a larger number of people with PD (Chapter Seven). However, at this stage it was of interest to know whether people tackled the test as intended by the researcher (i.e. whether participants understood what was required of them) and how much space people with PD required when turning from a standing-start. To summarise then, the aims of this study, in order of priority, were:

1) As in the *Healthy Adult Study*, to use motion-analysis tools available to validate the video-based analysis and measure additional components of the SS-180.
2) To identify any hazards before taking the SS-180 into the home environment, and
3) To begin to construct a picture of how people with PD turn from a standing-start.

6.2 Methods

6.2.1 Recruitment

Permission to conduct the study was given by the Local Research Ethics Committee (**Appendix 2**). A sample of people with PD who had been identified by the researcher seven years previously and participated in two earlier studies was approached (see **Appendix 3**). A letter was sent to the GP of everyone who had participated in a study two years earlier, requesting permission to contact his or her patient. With the GP's permission, a letter was sent to the potential participants, informing them about the study and inviting their participation. Individuals were encouraged to bring someone else with them to the appointment should they wish to do so.

A reply slip and a stamped, addressed envelope was sent out with the invitation. People who expressed an interest in the study were then contacted by telephone and an appointment arranged. Return travel by taxi was offered, arranged and paid for by the researcher. Potential participants who attended the laboratory were told more about the study and given an opportunity to ask questions; when they were satisfied that they wished to take part they were asked to give their written consent. To be eligible for inclusion in the study, participants had to have a consultant's diagnosis of PD, be community dwelling and able to walk without the assistance of another person (i.e. Hoehn and Yahr Grades I - IV).

6.2.2 Procedure

6.2.2 a Measures

Age, Sex, Height and FR were recorded and Height-adjusted FR (FR%Height) calculated as in the *Healthy Adult Study*. Four measures of PD duration and severity were recorded. PD Duration was defined as the number of years since the diagnosis was made. Severity was measured using the Hoehn and Yahr Grades (Hoehn and Yahr, 1967), the Unified Parkinson's Disease Rating Scale (UPDRS; Lang and Fahn, 1989) and the Self-assessment Parkinson's Disease Disability Scale (SAS; Brown et al, 1988 and 1989); see **Appendix 6**. Prescription drug use was documented (**Appendix 7**). Finally, the participants were asked a number of questions about fall-events (actual falls and near-misses) and turning, from which the following was ascertained:

- The number of falls over the past 12 months, their locations, the activity in which the faller was engaged, apparent cause and the landing (i.e. direction or injury).
- Other falls since diagnosis, fall-related injuries, worries or behavioural changes.
- The frequency of near-misses and the circumstances under which they had arisen.
- The progression of any difficulties turning round or steering when walking. Factors exacerbating difficulty turning and the consequences of difficulty turning and the management of difficulty turning.

All of the participants completed the SS-180 (following the protocol in Section 4.2) midway between doses of their dopaminergic drugs, to improve comparability between assessments, an approach used in our previous studies (Ashburn et al, 2001c).

6.2.2 b Data Analysis

The aims of the investigation did not demand more than a description of the sample's performance. Therefore, the data collected were summarised and summary statistics are presented (with inter-quartile ranges to illustrate the spread of values around the median). Spearman's Rank Correlation Coefficients were calculated to measure the strength of the association between FR and Height-adjusted FR. In the *Healthy Adult Study*, the correlates of turning were explored and Age and Balance found to be significant. These two variables were explored in the current analysis but the statistical significance of any apparent relationship was not tested. Additionally, the correlations between turning and disease duration and severity were explored. The responses to the questions about fall-events were collated and summarised; comments about those *associated with turning* are presented in the results section. The responses to the questions about turning were collated and summarised and are also presented.

6.3 Results

6.3.1 The Sample

Permission was sought from local GPs to contact 26 people with PD. Two GPs failed to respond, so their three patients could not be approached. One potential participant had died, one was in hospital and considered unlikely to be discharged home and one had changed GP. Therefore, twenty people were invited to take part in the study, only three of who failed to respond. Ten people withheld their consent, most of who gave a reason for so doing. Three initially agreed to take part but one became anxious about coming to the Hospital, one was busy until later in the year and, when contacted, one man said that it would be 'too much stress' so *he* did not want his wife to participate. Two were no longer able to leave their homes; one offered to participate if the research could be conducted in her home. One described herself as no longer safe on her legs and one could only manage to walk a few steps with assistance; both may have been ineligible to participate anyway. Three people did not indicate why they would not participate. Just seven of the 20 people approached (35%) agreed to participate.

The three men and four women ranged in age from 63 to 85 years (**Table 6.1**). Median participant height was 160.5cm (IQR 153.5 - 165) and median FR was 15.3cm (IQR 10.3 – 26.7). FR and FR%Height were very closely correlated ($r_s = 0.964$, see **Appendix 4**): throughout the chapter, 'Balance Control' will be taken to refer to the latter. The men were slightly older than the women were (medians 79 v 70.5) and had a slightly shorter height-adjusted FR (medians 9.1% v 11.4%).

Table 6.1: Sample Characteristics (n = 7 people with PD)

ID	Age	FR%Height	UPDRS	SAS
1	85	14.4	5	30
2	77	6.2	25	68
3	69	17.8	15	48
4	79	9.1	37	59
5	82	9.5	37	62
6	72	13.2	15	53
7	63	6.7	26	9
Mean (SD) *Median (IQR)*	*75.3 (7.7)* *77 (69 – 82)*	*11.0% (4.3)* *9.5% (6.7% – 14.4%)*	*22.9 (12.0)* *25 (15 - 37)*	53.3 (13.4) 56 (43.5 – 63.5)

Hoehn and Yahr Grades II – IV were represented in the sample (1 Grade II, 5 Grade III, 1 Grade IV), UPDRS Scores 5 – 37 and SAS Scores 30 - 68. The men had slightly more severe PD and rated themselves slightly more disabled than the women; the men's median UPDRS score was 25 and median SAS score 59, the women's median scores were 20.5 and 53, respectively. Five participants demonstrated bradykinesia, rigidity, resting tremor *and* postural instability when tested. Disease Duration (years since diagnosis) ranged from 7 to 22 years (mean 10.6 ± 5.6; median 8, IQR 7-14); the men had been diagnosed a median seven years, the women a median 8.5 years. Six participants used antiparkinsonian drugs (**Appendix 7**) and five answered questions about their response to medication and symptom fluctuations: three reported a noticeable response to their drugs and four reported noticeable fluctuations in symptom severity.

Four participants (57%) had fallen more than once in the preceding 12 months: the median number of falls experienced in the preceding 12 months was two (IQR 0 - 4). In this sample, balance control did not appear to correlate with age ($r_s = 0.143$), disease duration ($r_s = -0.259$) or the UPDRS ($r_s = -0.600$) but it was more closely correlated with the SAS ($r_s = -0.886$); better balance was associated with less self-assessed disability (see **Appendix 8**).

6.3.2 How People with PD Turned

The SS-180 was completed midway between doses: the median time since the last dose of a dopaminergic drug was 150 minutes (IQR 120 – 190 minutes).

The participants adopted similar starting positions before the DU Turns and DS Turns (**Table 6.2**). The median separation between the heels was less than 8% of body height and the median A-P difference was less than 1% in both conditions. Five participants (71%) turned first in the direction of their dominant hand. In the DU Turn, four participants (57%) first moved the foot on their dominant side and, in the DS condition, two participants (29%) first moved the foot on their dominant side.

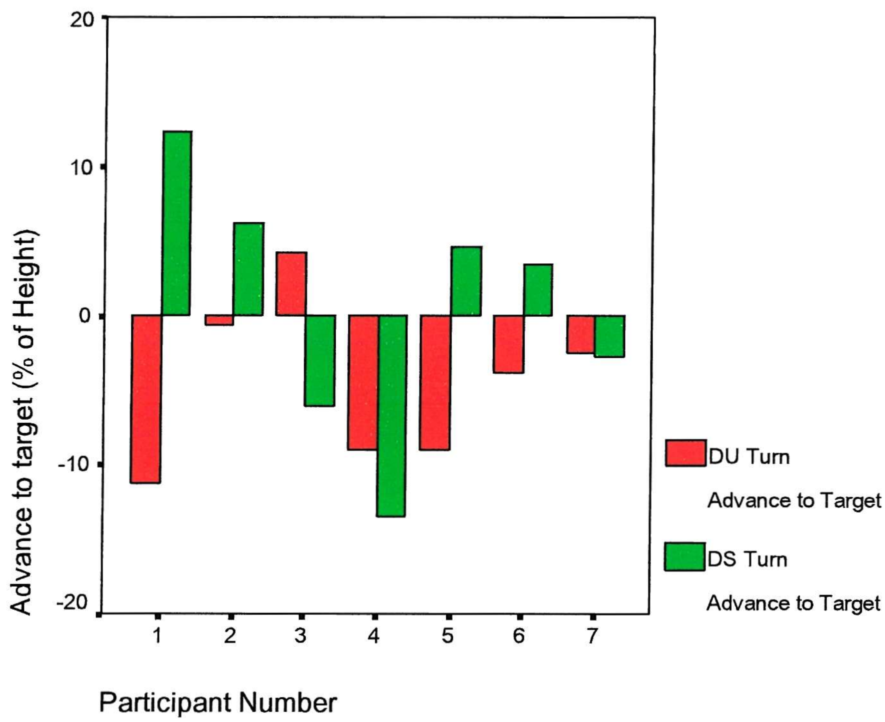
Table 6.2: Performance of the SS-180 by People with PD (n = 7)

Variable	Value	Direction Unspecified (DU) Turn	Direction Specified (DS) Turn
Heel Separation (% of height)	Median (IQR)	7.4 (6.9 – 8.4)	7.7 (6.9 – 7.8)
Heel A-P Difference (% of height)	Median (IQR)	0.4 (0.2 – 1.3)	0.5 (0.2 – 0.7)
Turning Steps	Median (IQR)	7 (4 - 13)	5 (5 – 12)
Turn Time	Median (IQR)	4.2 (2.5 – 6.9)	4.0 (2.3 – 7.0)
Turn Type	Delayed Onset Incremental Lateral	01 (14%) 05 (71%) 01 (14%)	02 (29%) 05 (71%) -
Turn Quality Score	Median (IQR)	3 (3 - 4)	4 (1 - 5)

As can be seen in **Table 6.2**, the DU and DS Turns were completed taking a similar number of steps in similar times. The overall number of Turning Steps taken during the SS-180, i.e. (DU Steps + DS Steps) / 2, was a median 6.0 (IQR 4.5 – 11.0). The overall Turn Time taken, i.e. (DU Time + DS Time) / 2, was a median 3.9s (IQR 2.4s – 7.0s). The numbers of Steps taken to complete both turns were closely correlated ($r_S = 0.852$) as were the Times taken ($r_S = 0.857$), see **Appendix 5**. The men tested tended to take more Turning Steps (medians 7.0 *v* 3.6) and longer to turn (11.0s *v* 5.8s) than did the women.

In five of the 14 turns demonstrated (36%), the participants commenced straight forward gait when they were further away from the target than they had been in the starting position (see **Figure 6.1**). Four participants (57%) advanced further towards the target during the DS Turn than during the DU turn (median DS advance *3% nearer* the target *v* median DU advance *4% away* from the target). Men and women made similar progress toward the target when turning (median 4.8% of height nearer the target v 2.7%).

Figure 6.1. Advance to target while turning. Bars above zero (i.e. positive values) indicate that the distance from the starting position to the target *increased* prior to the onset of straight forward gait.



Ten of the 14 Turns demonstrated (71%) were of the Incremental Type. Five participants (71%) demonstrated the same Type under both conditions while two men changed Type (**Table 6.3**); four people (57%) changed the movement-initiating foot.

Table 6.3: DU and DS Turn Types (n = 7)

ID	Type Maintained	DU Type	DS Type	Initiating Foot Maintained
1	No	Lateral	Incremental	Yes
2	No	Incremental	Delayed Onset	Yes
3	Yes	Incremental	Incremental	Yes
4	Yes	Delayed Onset	Delayed Onset	No
5	Yes	Incremental	Incremental	No
6	Yes	Incremental	Incremental	No
7	Yes	Incremental	Incremental	No

Those who maintained and changed Turn Type had performed their DU Turns similarly, the former in a median of seven steps in 4.2s and the latter in a median of eight steps in 4.3s. There was a greater difference in the performance of the DS Turn: those who changed Turn Type took a median 14.5 steps in 5.8s, whereas those who had maintained Type took only a median 5 steps in 4.0s. Those who maintained Turn Type were slightly younger (median 72) than those who changed Type (81). The five participants who maintained Turn Type demonstrated similar balance control (median 9.5%) to the two who changed (10.3%). Those who maintained Turn Type had slightly more severe PD (URS median 26, SAS median 53) than those who changed Type (medians 15 and 49, respectively).

Although the Turn Quality Scores changed little from the DU to the DS Turn (median change 0; IQR –2 to 1) there were a number of changes in the individual items. In **Table 6.4**, the five constituent items are presented in separate rows. The columns show how many of the seven participants were rated the same under the DU and DS conditions and how many were rated differently under each condition. Under the heading 'Same Rating', the participants who 'passed' and who 'failed' the item are split. For example, with respect to 'Continuity', four participants achieved the same rating under both conditions; three turned continuously under both conditions, while one was discontinuous under both conditions.

Under the heading 'Different Rating', the participants whose performance 'worsened' when the direction of turn was specified and those whose performance 'improved' are split. For example, with respect to 'Continuity', three participants achieved different ratings under the two conditions; one was rated as discontinuous only during the DS Turn and two who had demonstrated discontinuity turned continuously during the DS Turn.

Table 6.4: Turn Quality Scores under DU and DS Conditions (n = 7)

Item	Same Rating on DU and DS Turn		Different Rating on DU and DS Turn	
	Both = 1	**Both = 0**	**DS = 0**	**DS = 1**
Posture	1 / 7	2 / 7	2 / 7	2 / 7
Stability	4 / 7	2 / 7	1 / 7	0
Continuity	3 / 7	1 / 7	1 / 7	2 / 7
Independence	5 / 7	1 / 7	1 / 7	0
Clearance	4 / 7	3 / 7	0	0

With the exception of the individuals who scored one under both conditions (highlighted in green in the table), the other participants scored zero during the DU and/or the DS Turn. That is, at some point during the SS-180, six participants became more flexed as they turned, four lacked continuity of movement, three were unstable, three failed to clear the ground with their feet and two were unable to turn independently.

6.3.3 The Turn Types

Table 6.5 details the three Turn Types demonstrated by the sample (see **Appendix 1** for visual representations of each Type) and summarises the age and balance control of the participants who demonstrated each Turn Type.

The one Lateral turn was completed faster than all but one of the other turns (one Incremental Turn took 1.3s); it was initiated with the outside foot and complete in three steps. The first steps were as long as they were wide, moving the participant away from the target by a distance equivalent to 8% of his height. After turning, straight forward gait commenced at a distance equivalent to 11% of the participant's height nearer the target.

Table 6.5: Turn Type Frequency, Turning Steps and Times.

Variable	Value	Turn Type Lateral	Incremental	Delayed Onset
Turns	/ 14	1 (07%)	10 (71%)	3 (21%)
Participants	/ 7	1 (14%)	6 (86%)	2 (29%)
Age (years)	Median	85	75	78
	Range		63 – 85	77 – 79
FR%Height	Median	14.4	11.4	7.7
	Range		6.2 - 17.8	6.2 – 9.1
Duration (years)	Median	7	7.5	14.5
	Range		7 – 14	7 – 22
UPRDS	Median	5	20	31
	Range		5 – 37	25 – 37
SAS	Median	30	50.5	63.5
	Range		9 – 68	59 – 68
Time (s)	Median	1.7	3.9	7.2
	Range		1.3 – 7.0	6.7 – 10.2
Steps	Median	3	5.5	14
	Range		3 – 13	8 - 26
Turning-Step 1 *	Lateral	7	4.5 (0 - 7)	2 (0 – 3)
	A-P	7	2 (0 - 8)	-1 (0 – -4)
Turning Step 2 *	Lateral	6	8.5 (2 - 16)	2 (0 – 3)
	A-P	8	2.5 (18 - -3)	0 (0 - -6)
Final Turning-Step *	Lateral	15	7.5 (1 - 13)	11 (10 – 12)**
	A-P	-11	-2 (12 - -9)	-9 (6 - -14)

* Figures are medians (with range). ** n = 2, one CODA marker failed.

Half the Incremental Turns were initiated with the outside foot. Turning took at least five steps in 80% of cases; the first steps were small and the participants made little progress toward the target. The median distance travelled while turning was just 2% of the participant's height: they were still at the starting position, although they had turned to face the target.

Delayed Onset Turns were slow and all initiated with the outside foot. Turns took at least eight steps; the first of which brought about negligible change in foot position in any direction. The median distance travelled while turning was equivalent to 9% of the participant's height.

The participants who demonstrated different Turn Types were of similar ages. The Lateral turner had one of the longest reaches and the Delayed Onset turners the shortest median reach. Likewise, the Lateral turner had been diagnosed the least time and had low UPDRS and SAS scores while the Delayed Onset turners had been diagnosed the longest median number of years and had the highest median UPDRS and SAS scores of the three Turn Types. The DU Turn Type appeared related to Hoehn and Yahr Grade: the Lateral Turner was at Grade II, the five Incremental Turners were at Grade III and the Delayed Onset Turner was at Grade IV.

6.3.4 The SS-180, Balance Control and Age

The strengths of the associations between balance and age and Turning Steps and Turn Time are shown in **Table 6.6**. While balance appeared to be associated with the performance of a standing-start turn, in this sample age clearly was not. The associations between balance control and age and Turn Type were shown in Table 6; neither balance control nor age appeared to correlate with the Turn Quality Scores.

Table 6.6. Correlation between Balance, Age and Section 1 of the SS-180 (n = 7)

		DU Turn		DS Turn		Mean	
		Time	**Steps**	**Time**	**Steps**	**Time**	**Steps**
FR % Height	r_s	-0.536	-0.536	-0.750	-0.667	-0.786	-0.607
Age	r_s	0.036	0.036	0.000	0.074	-0.036	0.000

6.3.5 The SS-180, Disease Duration and Severity

In this sample, disease duration was not associated with any section of the SS-180. The strengths of the associations between the UPDRS and SAS and Turning Steps and Turn Time are shown in **Table 6.7**: both variables were clearly associated with the performance of a standing-start turn.

Table 6.7. Correlation between the UPDRS, SAS and Time and Steps (n = 7)

		DU Turn		DS Turn		Mean	
		Time	**Steps**	**Time**	**Steps**	**Time**	**Steps**
UPDRS	r_s	0.764	0.764	0.764	0.698	0.764	0.673
SAS	r_s	0.771	0.771	0.943	0.986	0.886	0.886

The associations between the UPDRS and SAS and Turn Type were shown in **Table 6.5**; neither appeared to correlate with the Turn Quality Scores.

6.3.6 Questions about Falls and Turning

Falls and Near-misses

During the last 12 months, one participant had fallen once and four had fallen repeatedly (twice, three, five and six times). Three of the four repeat-fallers had fallen turning. One woman fell when she turned to look at someone while still walking ("being nosy"). One woman fell turning in her bedroom and another fell turning in her kitchen. Although one man had not fallen or nearly fallen in the last year, he had fallen once since he was diagnosed with PD; it happened as he was turning round in his bathroom. Six participants reported near-misses during the previous 12 months and three highlighted turning as an activity they associated with nearly falling, or as one put it "stumbling". One described "a few" near-misses turning when his left leg did not move as anticipated.

Difficulty Turning

Six participants reported difficulty turning in standing. Four found turning at speed problematic: one said that turning quickly made him "take a step backwards" and three reported that turning at speed made their turning "worse". Two found turning in a confined space problematic. One man was surprised at how well he had turned in the laboratory and said "I don't think I'd have done it another day without falling": he found turning difficult when he could not "control" his turn "in advance". Another man found a sudden turn more difficult than steering while walking: he managed "dramatic changes in direction" by taking short steps backward and had noticed that his turning seemed "worse" if he felt in danger or was carrying anything.

One woman no longer felt able to "just stop and turn". She frequently froze when turning and managed her difficulty by stopping walking, then turning while holding on, then resuming walking. Another woman described herself turning "gingerly", though she found turning left "much better and safer".

6.3.7 Summary of Findings

A sample of seven people, of median age 77, was studied; they had been diagnosed with PD a median of eight years and the majority were at Hoehn and Yahr Grade III.

How People with PD Turned

The sample adopted similar Starting Positions before the DU and DS Turns. The steps and times taken to complete both turns were closely correlated. The majority of participants turned in four or more steps (median 6.0, IQR 4.5 – 11.0), taking at least 2.5 seconds to do so (median 3.9s, IQR 2.4 – 7.0).

Incremental Turns were the Type demonstrated most often; Delayed Onset Turns and Lateral Turns were rarely observed among this sample. Five participants (71%) demonstrated the same Turn Type under both conditions and four participants (57%) changed their movement-initiating foot.

Turn Quality was scored from zero to five; zero indicated failure on all five items (i.e. *Continuity, Ground Clearance, Independence, Posture* and *Stability*) and five indicated that all five items were rated favourably. Turn Quality Scores ranged from one to five. Change from the DU to the DS condition was most commonly observed in *Posture* and *Continuity*.

As they turned, participants advanced to the target a median distance equivalent to less than 5% of their height; in one third of the turns demonstrated, straight forward gait commenced with the participants *further* from the target than they had been in the Starting Position.

Turn Types and the People Demonstrating Each One

Delayed Onset Turns were the Type completed slowest by this sample and necessitated at least eight Turning Steps, the first of which brought about a negligible change in foot position. The majority of Incremental Turns necessitated at least five Turning Steps: after the initial Turning Step with each foot, negligible advance toward the target had been made (equivalent to approximately 2% of participant height). The one Lateral Turn was one of the quickest turns demonstrated and complete in three steps, the first of which was a small lateral movement taken with the outside foot, widening the base.

Correlates of Turning

In this sample, neither age nor disease duration correlated with the performance of a standing-start turn but balance, disease severity and self-assessed disability correlated with some aspects, most notably the number of steps and time taken to turn but also the selection of Turn Type.

Reported Difficulty Turning

Three of the four repeat-fallers had fallen turning and one man's only fall since he was diagnosed with PD happened as he was turning. Half of the six participants who experienced near-misses, associated turning with nearly falling. Six of the seven participants reported difficulty turning in standing. Speed and confined spaces were the factors most commonly reported to exacerbate the difficulty.

6.4 Discussion

This small study was the first in which the SS-180 was used with people with PD, the group of people for who it was developed. There are many reasons why research on the movement disorders of people with PD should not be conducted *exclusively* in the laboratory and a larger study, conducted in people's homes, was planned to follow this one. This laboratory-based study can be considered a preliminary to the main investigation in which the performances of people with PD on the SS-180 will be explored. Briefly, the aims were:

1) To use the motion-analysis tools available in the laboratory.
2) To identify any potential hazards in using the SS-180 with people with PD, and
3) To construct a picture of how people with PD turn from a standing-start.

Each of these aims is discussed in turn below.

6.4.1 Using Motion Analysis in the Laboratory

While externally validating the video-based SS-180 was the primary reason for using CODA (see Section 4.3), an additional benefit was that measurements of the participants' base width prior to turning and turning step magnitude could be made.

Base width prior to turning was considered an important factor to explore in relation to turning because some researchers have suggested that, while a wide base might stabilise straight forward gait, it might add to the difficulty of turning (Charlett et al, 1998). However, people with PD characteristically have a relatively narrow base in relation to healthy subjects. If the participants in the current study were found to adopt a different starting position to the healthy adults who had previously been recorded performing the same test under the same conditions, it would be a possible explanation for any turning differences observed. In the current study, however, the starting position adopted by the participants was very similar to that adopted by the participants in the *Healthy Adult Study*.

Furthermore, the participants took up starting positions for the second turn that they were required to demonstrate (the DS Turn) that were very similar to the positions adopted for the DU Turns. There was no suggestion that people modified their base width in the light of their experience of performing the SS-180. People were permitted to use walking sticks during the test; while it was not apparent that anyone increased the separation between their heels to widen (and perhaps stabilise) their base, participants might have modified their base by positioning their walking aids differently when they came to attempt the DS Turn.

A limitation of using only one CODA Unit (as discussed in Section 5.4) was that base width was inferred from the separation of the CODA heel markers only; the toe markers being invisible in the starting position. It is possible that people modified their base width by modifying the angle between their feet. With a second CODA Unit, it would be possible to record a more complete picture of the starting position.

The magnitude of individual turning steps and the overall distance advanced toward the target while turning could also be measured from CODA. The findings from this study have revealed that, even when people with PD demonstrate the same Turn Types that are seen in people without the condition, the way in which they complete those turns is somewhat different. For example, the one Lateral Turn demonstrated in this study was accomplished in a similar way to the Lateral Turns demonstrated in the *Healthy Adult Study* with one exception, the progress made toward the target. The Lateral turner with PD travelled a distance equivalent to just 11% of his height, whereas three-quarters of the healthy adult Lateral turners travelled at least 32% of their height. Although based on a sample of one, this finding raises the possibility that an early adaptation to turning made by people with PD is to reduce the distance travelled while completing the rotational component of a standing-start turn (see also Section 6.4.3).

Only four markers were used to record movement. It was not the intention to record in detail the movement at individual joints during turning. The SS-180 requires only a gross count of Turning Steps and a decision made about Turn Type based on the number of steps, their size and direction. It would have been possible to use a greater number of CODA markers to generate a larger data set but doing so would have had disadvantages. Firstly, in attempting to record an individual's natural movement, the less encumbered by equipment the subject is, the better. There is evidence to suggest that people alter their gait when they walk with their arms held clear of markers attached around the hips. The four CODA markers used were barely noticeable to the subject from the time they were attached to their shoes to the time they were removed. The measurements taken from the markers used answered the research questions around which the study was designed and did not generate superfluous data. Using more markers would have added to the time demanded of the participants; another reason for using a minimal set.

A related issue is the context effect; the changes in mobility (often positive) that people with PD experience when being tested under very contrived conditions, i.e. when they are concentrating on performing one task well, while being recorded doing so in a quiet and uncluttered environment. Previous experience had shown that people with PD were very likely to perform at an artificially high level when participating in laboratory-based research. Nieuwboer et al (1998) found little evidence of many reported motor symptoms (e.g. freezing) when they tested people with PD under controlled conditions. The data collection procedure was designed to avoid cueing the participant's to perform anymore than was strictly necessary. The recording equipment was turned on and left on before testing began and efforts were made to ensure that the participant was not made to feel rushed into reaching the target as quickly as possible when instructed to begin. Even so, one man was surprised at how well he had turned in the laboratory and he said, "I don't think I'd have done it another day without falling". For this reason, the study was designed to lead into a larger one in the more natural setting of people's own homes.

Another disadvantage of using laboratory-based tools is that severely disabled people are excluded from participating in research by the difficulties inherent in reaching the laboratory. Research based exclusively in laboratories will be of very limited application. Just a third of the individuals approached took part in the study. The seven participants were all rated at the same Hoehn and Yahr Grade as they had been two years earlier, when they had last participated in a study conducted by the researcher. In keeping with prior experience, it was people at the more severely disabled end of the spectrum who did not attend the laboratory. For example, the three people who were not contacted had all been at Grade IV two years earlier as had the three non-responders, the two who were virtually housebound and the two whose gait was seriously impaired. Being able to reflect on the success (or otherwise) of recruitment in the light of additional information about disease severity was one advantage of working with a known sample. A disadvantage was that because of how the sample was identified, none of the participants had been diagnosed any less than seven years. It was anticipated that in the home-based study to follow a proportion of the participants would be earlier in the disease course and provide a fuller picture of the way in which people with PD turn. Although the participants were predominantly at Hoehn and Yahr Grade III, the severity of individual signs was wide ranging, as was the level of self-assessed disability.

6.4.2 Potential Hazards Associated with the SS-180

In the *Healthy Adult Study* the SS-180 had proved very safe but among this sample a number of safety issues came to light: the opportunity to test people with PD in a safe environment prior to testing them in the community proved very valuable.

Asking questions about previous falls and known difficulties turning before asking anyone to perform the SS-180 alerted the researcher to any individual who raised concerns about his or her ability to turn safely. The participants were reminded repeatedly that they did not have to attempt every task asked of them, just as they were free to choose not to answer every question. The researcher stressed that they should only attempt the SS-180 if, having seen the test demonstrated, they felt safe to do so. Even so, it was necessary to stand close to the participants throughout the test and catch more than one who appeared at imminent risk of falling. Six of the seven participants recounted having difficulty turning and four recounted falling while turning but all seven were happy to attempt the SS-180. No one fell during the test but three people were clearly unstable and two required support. A second person stood by during the test when there was any doubt about a participant's safety.

No one complained of pain during the SS-180 but more than one participant sat and rested between trials as they experienced some fatigue. This experience illustrated that the test was challenging for people with PD and people who reported difficulty turning. This was a positive finding, lending validity to the test procedure. It emphasised the need to be cautious when carrying out the test in people's homes, particularly when working alone.

As in the *Healthy Adult Study*, the participants all appeared to understand the requirements of the test and carried out the procedure in the intended manner. The space in which to turn required by the participants was much as it had been in the *Healthy Adult Study*. No participant attempted to turn in such a wide arc that they were compromised by the physical constraints of the environment. There was no reason to modify the test protocol or the instructions before taking the SS-180 into the community.

6.4.3 How People with PD Turned

It is important to stress that this study was not intended to be the second half of a cross-sectional comparison of people with and without PD. However, as the only existing data with which to compare these findings came from the *Healthy Adult Study* presented in the previous chapter, reference to the findings of that investigation will be made throughout the discussion. For example, the *Healthy Adult Study* showed that balance and age were key factors in determining how an individual turned from a standing-start.

Clearly, the sample described in this study had a much shorter height-adjusted FR than the healthy adults discussed earlier (medians 9.5% *v* 19.2%) and were much older (medians 77 *v* 40). Therefore, one would expect to see quite different performances of the SS-180 by this small sample of people with PD. Despite its small size, the sample encompassed a wide-ranging group of individuals with respect to disease duration and severity, e.g. the lengths of time since diagnosis spanned 15 years. As in the study of healthy adults, this study revealed a very close correlation between FR and height-adjusted FR.

Unlike in the *Healthy Adult Study*, height-adjusted FR did not correlate with age. Balance control also appeared unrelated to disease duration or severity (as measured by the UPDRS) in this sample. However, those with better balance rated themselves as significantly less disabled than did those with worse balance. In the Healthy Adult Study, balance correlated with the Turning Steps and Turn Time taken during both the DU and DS Turns and with the Mean Turning-Steps and Turn Time. In this study, the correlation coefficients were stronger in every case, though only statistically significant with respect to the Mean Turn Time. The size of the samples would explain this apparent contradiction. The number of individuals demonstrating each Type was very small but there was a suggestion that people with a shorter reach demonstrated the Delayed Onset Turns, people with slightly better balance demonstrated Incremental Turns and the individual with almost the longest height-adjusted FR demonstrated the one Lateral Turn.

In the *Healthy Adult Study*, the individuals who demonstrated Pivotal and Toward Type Turns had the longest median height-adjusted FR of the sample; these two Turn Types were not observed in the current study. This finding added weight to the assertion made in the previous chapter that these Turn Types are highly demanding of balance control. Thigpen et al (2000) also considered 'an absence of pivot' to be an indicator of difficulty turning. It may be that pivoting over a planted foot is a very difficult manoeuvre to complete when balance is impaired and that people unable to pivot pick up and put down each foot several times to accomplish the same reorientation prior to walking toward the target. There is still no suggestion that balance control, however, determines whether or not an individual needs to change Turn Type when direction is imposed.

This study also supports the finding that people with better balance control are able to travel nearer to their target while turning than are people with worse balance. As a group, the people with PD studied made less progress to the target while turning than did the healthy adults described in Chapter Five. Stability was the only factor measured during this study to correlate with any part of the Turn Quality Score. In Ashburn et al's study (2001b) one third of the participants were adjudged to be unstable as they turned 180° during a functional task, tea making. In the current study, apparent instability was rare: two participants were unstable turning in both directions and another only appeared unstable when turning in the specified direction. It is perhaps surprising then that such a stable sample demonstrated turns that were so different to those demonstrated by healthy adults.

In this small study, disease duration was only correlated with the progress made toward the target while turning. Rather unexpectedly, the individuals who had been diagnosed longest tended to make more progress toward the target while turning. The Turn Type goes some way to explaining this finding. The Hoehn and Yahr Grade showed the predicted relationship with Turn Type, though only in the DU Turn. The UPDRS showed some relationship with the performance of the SS-180. Those with more severe disease took more Turning Steps and longer to turn and made more progress away from the starting position with the initial Turning Steps than those with milder disease. Self-assessed disability was related to how the participants turned. Those who rated their disability highest took the greatest number of steps in the longest time while making most progress toward the target.

This is quite different to rating the severity of individual signs. SAS has an element of effort about it; perhaps it measures something more elusive that explains difficulty in PD (problem solving or strategizing, for example).

One of the most striking features of the *Healthy Adult Study* was the degree of similarity between the performance of the DU and DS Turns. In the current study too, the group adopted similar starting positions prior to each turn, took similar numbers of Turning-Steps in similar Turn Times, demonstrated similar Turn Types and achieved similar Section III Scores. Some people however deteriorated while some improved when the direction of turning was specified; this topic will be revisited in Chapter Eight. Ground Clearance was the only item in Section III of the SS-180 that was demonstrated with 100% consistency in both directions; three of the seven participants lacked ground clearance on turning.

The second striking feature of the way in which healthy adults turned from a standing-start was the efficiency of the manoeuvre. In both studies, approximately 70% of the participants turned first toward their dominant hand. The initial turning step was more frequently taken with the *inside foot* in the Healthy Adult Study (66%) and more frequently taken with the *outside foot* in the current study (64%). Could it be a fundamental flaw in planning turning that the outside foot is used to initiate turning, or could moving the outside foot first be a stability-enhancing modification? In this study, participants took more steps than did the healthy adults (medians 6.0 v 2.5) and longer to turn (3.9s v 1.5s). Morris et al (2001) reported that the individual with PD they studied took more steps than their two controls in every turn that was compared. The assertion by Simpson et al (2002) that people with PD may take between 18 and 20 steps to turn 180° on-the-spot (unsupported by data in their publication) seems even more surprising in the light of these findings: only one turn demonstrated in this study required that many steps.

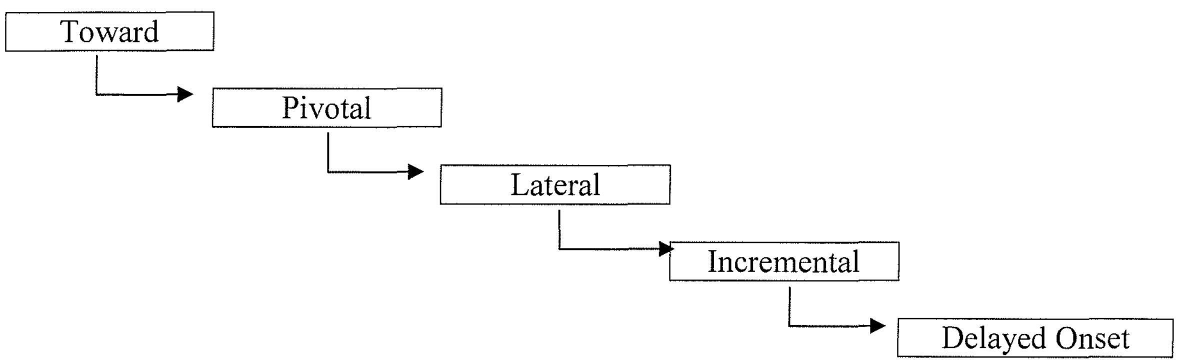
Another component of efficiency was the combination of the two elements of the test, i.e. rotation and translation toward the target. In this study, participants did not advance as far while turning as did the healthy adults in either the DU Turn (medians 3% nearer the target v 52% nearer) or the DS Turn (4% away from the target v 57% nearer). Turn Types demonstrated in the two studies were different. Incremental Turns dominated, and Delayed Onset Turns were unique to, the current study.

The expected pattern of Turn Types in relation to Hoehn and Yahr Grade (i.e. Lateral to Incremental to Delayed Onset) was mirrored by the changes seen when direction was imposed. When compelled to demonstrate a DS Turn, the Lateral Type turner changed to an Incremental Turn and one Incremental Turner changed to a Delayed Onset Turn. This will be discussed further in Chapter Eight.

When the findings of the Healthy Adult Study and the current study are considered together, a hierarchy of Turn Types begins to emerge (see below). Toward and Pivotal Turns are highly balance-demanding, yet efficiently accomplished and very dynamic, combing rotation with translation toward the goal. A Lateral Turn may be a way of making turning easier, broadening the base by moving the outside foot first.

Several smaller steps make turning safer still as each Turning Step covers only a small distance and hence requires little time spent in 'single-stance', so it may be a useful strategy as balance control diminishes; furthermore rotation is complete before walking commences. Finally the Delayed Onset Turn represents difficulty initiating any movement (particularly rotational). It is envisaged that in the home-based study, evidence will arise to support this notion. The studies were all cross-sectional; longitudinal study would be necessary to chart the changes in an individual's standing-start turns over time. It may be that movement through the hierarchy accompanies ageing and that PD accelerates that movement.

Figure 6.2. A Hierarchy of Turn Types



Incremental Turns were observed in both studies and the same adaptation, if that is what it is, was evident; the healthy adults travelled approximately one third of their height as they turned, whereas the participants with PD barely moved from the starting position.

Thigpen et al (2000) considered Turn Type to be a developmental change in response to 'subtle changes in balance'. The current study suggests that, while Type is maintained, the turn is completed increasingly 'on-the-spot'.

Coupled with the reliability studies discussed in Chapter Four, there is evidence to suggest that one might be able to measure the differences between people with and without PD on the SS-180. The difference between the groups studied in the laboratory was in the order of three Turning Steps and two seconds. This was important to ascertain before commencing the main investigation in people's homes; had the differences between the samples studied been smaller, a much larger main investigation sample size would have been required. The apparent gender differences that emerged from the current study were probably spurious. The group of three men who participated in the study was slightly older than the group of four women, had a slightly shorter height-adjusted FR and scored slightly higher on both the UPDRS and SAS, despite being diagnosed a slightly shorter time. In light of these differences, the tendency for men to take more steps and longer to turn is not surprising and probably not related to gender at all. As such, these findings do not lead one to conclude that men and women need be considered as separate groups in the main investigation.

6.5 Conclusions

The use of CODA revealed that the people with PD tested adopted similar starting positions prior to the SS-180 to the healthy adults studied previously but took smaller turning steps and advanced less far toward the target as they turned. Laboratory-based research has a number of advantages but it has drawbacks, too. The temptation to over-analyse a large easily acquired data set must be resisted, the unnatural context makes participants very aware of and attentive to what is being recorded and many people are deterred from participating by the effort involved in getting to the laboratory. The new test was challenging but the people with PD tested carried out the SS-180 in keeping with the protocol. This study highlighted the need for the individual conducting the test to a) take steps to ensure that people likely to fall are not put at risk and b) remain in close proximity to the participants who they do ask to attempt the test.

Although the sample size was small, a number of interesting findings emerged. Difficulty turning was a common problem among the sample tested. The standing-start turns of people with PD appeared quite different to those of people without the condition; it might be possible in the future to support or refute a diagnosis on the basis of the SS-180, if the difference is sufficiently great. People with PD tend to turn before they walk towards their target rather than combine the two components, particularly when having to turn in the direction that they did not choose to turn. Disease severity (particularly balance impairment) appears to be associated with how an individual with PD turns.

After the two laboratory-based studies described in this and the preceding chapter, a picture was beginning to emerge of how the standing-start turns of people with PD differed to those of controls. There was some evidence here to support the assertion of Steiger et al (1996) that difficulty turning comes from the 'inability to execute the sequence of axial movements required'. People with PD certainly seemed to break down the standing-start turn into distinct components and achieved the necessary rotation by taking several small Turning Steps. However, whether these features were 'inappropriate turning strategies', as Steiger et al suggested that deviations from the norm were, was debatable. Despite the history of difficulty turning among this sample of people with long-standing PD, all of them managed the SS-180, so arguably they deployed successful adaptations. However, a larger sample of people with PD was needed to strengthen or weaken the ideas presented in this chapter and an older sample of healthy adults was needed to serve as an appropriate comparison. In the following chapter, the main investigation, designed to meet both these requirements is discussed.

Chapter Seven

A Comparison of People with and without PD Performing the Standing Start 180° Turn Test

7.1 Overview and Introduction

The development of the SS-180 was described in Chapter Four. In the laboratory-based studies described in Chapters Five and Six the SS-180 demonstrated its external validity and acceptable reliability and proved workable and safe to use. It was, therefore, possible to build on the preliminary findings by using the new tool in people's homes, accessing a larger, more varied sample. In this chapter, hypotheses about the way people with and without PD turn and the correlates of turning are discussed, alongside the issues surrounding the conduct of research in people's homes.

People with and without PD might turn differently because the physical abilities required to turn (e.g. balance control, range of motion, speed of movement) are commonly impaired in PD. The laboratory-based studies described previously provided some evidence to support this hypothesis: for example, Turn Time was longer in the PD group than in the healthy adult group and the frequency with which the Turn Types were demonstrated in each study also differed. The laboratory-based studies also supported the idea that turning is a highly balance-demanding activity, as a) height-adjusted FR correlated with the performance of the SS-180 and b) the groups with and without PD differed in height-adjusted FR and the way that they turned. Testing a larger sample of people was required to confirm the significance of the early findings.

Testing more people with PD, particularly individuals who had been recently diagnosed, would increase confidence in the inferences that could be drawn about how people with PD turn. The small group of people with PD tested in the laboratory had a median age of 77 years and had been diagnosed a median eight years. The healthy adults tested in the laboratory had a median age approximately half that of the people with PD studied. Therefore, an older sample would be more appropriate for comparison and allow a fuller picture of the way healthy adults turned to be documented, as age appeared to be a determinant of the way in which healthy adults turned.

In the small study of people with PD conducted in the laboratory, PD duration and severity appeared to be associated with the way people turned but the sample was too small to allow a reasonable investigation. I hypothesised that people who had been diagnosed a long time and had severe signs and symptoms of PD would demonstrate dysfunctional turning more frequently than more recently diagnosed individuals with a milder disease presentation of the possible associations between PD duration and severity and the ability to turn. With a larger enough sample, it would be possible to explore the associations between turning and the severity of individual signs of PD, not simply overall disease severity. By so doing, it might be possible to suggest which elements of PD contribute to dysfunctional turning.

In summary, this investigation was undertaken to access a larger, more varied sample of people with PD than was studied in the laboratory and to access a group of age-matched controls. The investigation allowed direct comparison of the way people with and without PD performed the SS-180 and further exploration of the correlates of turning. Therefore, the aims of this study were to describe and compare the turns of people with PD and healthy controls and test the following hypotheses:

1. PD duration and severity are key determinants of the way people with PD Turn.
2. Age and balance are key determinants of the way people without PD turn.
3. People with PD take more Turning Steps and a longer Turn Time than healthy adults, demonstrating different Turn Types and scoring lower on Turn Quality.

7.2 Methods

7.2.1 Recruitment

A sample size calculation showed that a sample of 28 people would provide the proposed investigation with 80% power at the 5% significance level (see **Appendix 9**).

Having secured the permission of the Local Research Ethics Committee (**Appendix 2**), the recruitment of participants was achieved via a local branch of the PD Society. Initial contact was made with the Branch Secretary, who later met with the researcher to discuss the protocol and paperwork that would be sent out to the members. A second telephone discussion also took place between the Branch Chairman and the researcher. Both officials were happy for the researcher to contact the members. The Secretary prepared a mailing list for the researcher to use, indicating wherever more than one member was listed at an address which member was the individual with PD. This information allowed the researcher to address correspondence to the appropriate individual.

Invitations to participate in the study were sent out (**Appendix 3**) to the 48 individuals with PD on the mailing list. A reply slip (**Appendix 3**) and stamped, addressed reply envelope was sent out with the letter of invitation and the researcher's contact telephone number was given so that potential participants could speak to the researcher in person. People who expressed an interest in participating in the study were contacted and an appointment made for the researcher to visit them at home. To be eligible for inclusion in the study, participants had to have a diagnosis of PD, be community dwelling and able to walk without the assistance of another person (i.e. Hoehn and Yahr Grades I - IV). Controls were recruited in the same way. The majority of the sixteen controls invited to participate were the spouses of the people with PD recruited.

7.2.2 Data Collection Procedure

Data were collected during a single visit to each participant. When the spouse, for example, was *also* a participant (in the Control Group), another appointment was arranged to see him or her on a separate occasion, to avoid over-burdening the participants in one long session.

Age, *Sex*, *Height* and *Functional Reach* were recorded and *Height-adjusted FR* (FR%Height) calculated as in the *Healthy Adult Study*. FR was measured using either a ruler or a folding meter rule, temporarily stuck to a convenient wall. The four measures of PD duration and severity were recorded, as in the *PD Laboratory Study*:

- Disease Duration (number of years since diagnosis).
- Hoehn and Yahr Grades.
- The Unified Parkinson's Disease Rating Scale.
- The Self-assessment Parkinson's Disease Disability Scale.

Drug use was also documented. The participants were asked the same questions about fall-events and turning as outlined in the previous chapter (Section 6.2), covering fall-events (location, associated activity, cause and landing, injuries and related worries) and difficulty turning (consequences, exacerbation and management). As with the PD Laboratory Study, the interviews *presented* here will be *discussed* in Chapter Eight.

The SS-180 was completed at a point midway between doses in the largest space available, following the protocol outlined in Section 4.2.4. Adequate space was needed a) to ensure that the video camera had an unhindered view of the participant turning and b) that the researcher could stand close by to assist the participant if they appeared unstable at any point. In most cases, the test was completed in a reception room and in every case the surface underfoot was carpet.

7.2.3 Analyses

7.2.3 a Describing and Comparing the Groups

Summary statistics are presented for: age, gender, height, FR, height-adjusted FR (balance control) and, where appropriate, the Hoehn and Yahr Grades, UPDRS, SAS, falls in 12 months and the number of prescription drugs taken daily. The drugs taken by the PD Group are summarised in **Appendix 7**. Spearman's Rank Correlation Coefficient (r_s) was used to examine the relationship between FR and Height-adjusted FR and to measure the strength of the associations between balance control and age, disease duration and disease severity. The age and sex structures of the groups were compared and the difference in the balance control of the groups was tested using the Mann-Whitney Test.

7.2.3 b Describing and Comparing Turns

Summary statistics are presented for the number of Turning Steps, Turn Time, Turn Types and Turn Quality Scores demonstrated during the SS-180 DU and DS Turns. The overall performance of the SS-180 is also summarised for both groups, i.e. the *mean* of the DU and DS Turning Steps, the *mean* Turn Time, the *overall* frequency of Turn Types and the *change* in Turn Quality Score from the DU Turn to the DS Turn. The Turning Steps, Turn Times and Turn Quality Scores demonstrated during the DU Turn were compared with the DS Turn using the Wilcoxon Test. Chi Square was used to examine the association between Turn Type and direction (i.e. DU or DS). The performance of the PD group was compared with the Control group's performance: differences in the Turning Steps, Turn Times and Turn Quality Scores demonstrated by the groups were compared using the Mann-Whitney Test. Chi Square was used to examine the association between Turn Type and group (i.e. PD or Control).

7.2.3 c Correlates of Turning

The possible associations between age and balance and, in the PD group, disease duration, the UPDRS and the SAS and Turning Steps, Turn Time and Turn Quality Score were assessed using Spearman's Rank Correlation Coefficient (r_S). The association between the categorical Turn Type and age, balance, disease duration and severity was explored using the Kruskal-Wallis Test.

7.3 Results

7.3.1 Recruitment and Sample Characteristics

Forty-eight members of the Winchester Branch of the PDS were approached. Four were ineligible to participate (two in nursing or residential homes and two unable to walk independently) and 24 people responded positively. Eleven controls were recruited from the 16 approached. Twenty-three people with PD took part in the study (age range 46 - 84); 14 men and 9 women (**Table 7.1**): all 23 taking antiparkinsonian medication (see **Appendix** 7) and 16 (70%) also taking other types of prescription medication.

Nineteen demonstrated bradykinesia: all 19 demonstrated at least two other cardinal signs. Those who did not demonstrate bradykinesia all reported asymmetry and a positive response to medication. Fourteen participants (61%) reported the asymmetrical onset and/or presentation of symptoms. Sixteen of the 21 participants questioned about their drug regime (76%) reported a noticeable response to their medication and 16 reported fluctuations in symptom severity. Median participant height was 167.8cm (IQR 160 – 173.1) and median FR was 18.9cm (IQR 15.2 – 26.7, n = 22). FR and FR% Height were very closely correlated ($r_s = 0.989$, $P = 0.000$); see **Appendix 4**. Fourteen participants (61%) had fallen more than once in the preceding 12 months: the median number of falls experienced in the preceding 12 months was three (IQR 1 - 4). The time since diagnosis ranged from one year to 25 years. One participant (4%) was at Hoehn and Yahr Grade II, 18 (78%) at Grade III and four (17%) at Grade IV. UPDRS Scores ranged from 9 to 38 (n = 22) and SAS Scores from 30 to 88. Mean number of prescription drugs taken was 4.3 (2.0); median 4 (IQR 3-6).

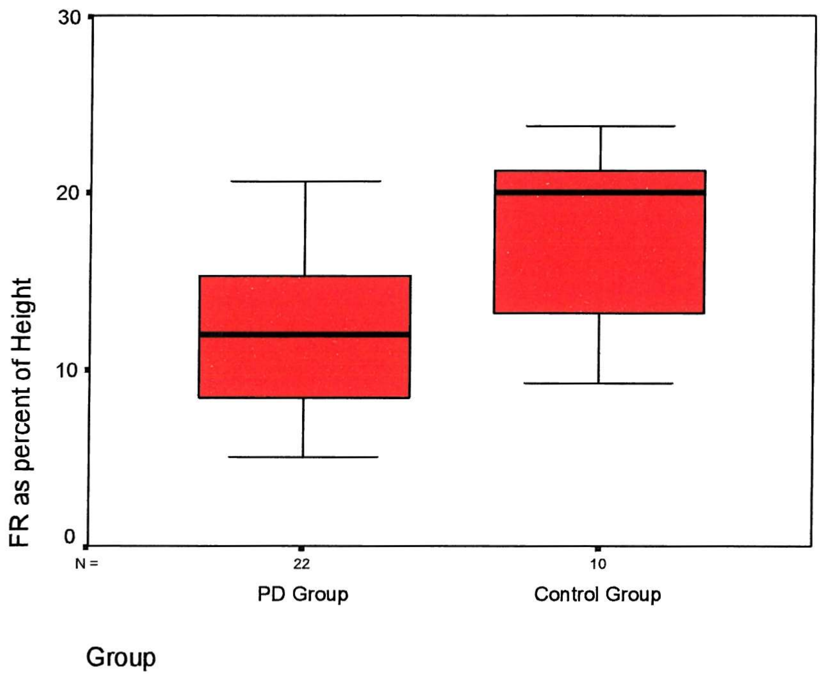
Table 7.1. Sample Characteristics: Main Study Participants (n = 33)

Variable	Value	People with PD (n= 23)	Controls (n=10)
Sex	M : F	14 : 9 (61% : 39%)	5 : 5 (50% : 50%)
Age (Years)	Mean (SD) Median (IQR)	67.7 (10.3) 68 (59 – 77)	70.0 (10.6) 69.5 (60.5 – 77.8)
FR%Height	Mean (SD) Median (IQR)	12.1% (4.2) 12% (8.3% – 15.5%)	18.1% (4.7) 20% (13.1% – 21.3%)
PD Duration	Mean (SD) Median (IQR)	8.3 (7.7) 4 (2 - 13)	n/a
UPDRS	Mean (SD) Median (IQR)	21.2 (7.4) 21 (15.8 - 27)	n/a
SAS	Mean (SD) Median (IQR)	55.7 (16.3) 56 (43 – 69)	n/a

Balance control did not correlate with age ($r_s = -0.239$, $P = 0.284$) or disease duration ($r_s = -0.021$, $P = 0.925$). However, people with more severe PD tended to have a shorter height-adjusted FR (i.e. worse balance) than people with milder PD: the correlation between balance control and the UPDRS was -0.401 ($P = 0.072$) and between balance control and the SAS -0.472 ($P = 0.026$).

Five men and five women without PD took part in the study (age range 56 - 89), see **Table 7.1**. Median participant height was 174.8cm (IQR 165.3 – 179.8) and median FR was 33.5cm (IQR 22.3 – 39.0). FR and FR%Height were very closely correlated (r_s = 0.948, P = 0.000, see **Appendix 4**) and balance control also correlated with age (r_s = -0.638, P =0.047). The proportions of men and women in both groups were similar and the groups were of similar age distributions. The controls had a longer height-adjusted FR (i.e. better balance control) than did the people with PD (P = 0.004; **Figure 7.1**).

Figure 7.1. Height-adjusted FR: People with and without PD



7.3.2 How People with PD Turned

One participant did not feel that he could safely attempt the FR test or the SS-180. He was at Hoehn and Yahr Grade IV, had fallen approximately once a month over the previous year, scored well above the sample average on the SAS (scoring 88) and UPDRS (scoring 38) and had severe rigidity, postural instability and bradykinesia. The SS-180 was completed midway between doses: the median time since the last dose of a dopaminergic drug was 115 minutes (IQR 90 – 190 minutes).

7.3.2 a The DU and DS Turns

As shown in **Table 7.2**, the Turning Steps taken during the DU and DS Turns were similar (both medians 4; P = 1.000), as were the Turn Times (medians 2.3s and 2.0s; P = 0.262). The close correlations between the Turning Steps ($r_s = 0.8$) and Turn Times ($r_s = 0.8$) taken during both Turns are highlighted in **Appendix 5**. Eight people (36%) took more steps during the DS Turn and ten (45%) turned faster.

Table 7.2. DU and DS Turns: 22 People with PD

SS-180 Item	Values	DU Turn	DS Turn
Turning Steps (n)	Mean (SD) Median (IQR)	4.7 (2.7) 4 (3 – 5)	4.7 (2.5) 4 (3 – 5.5)
Turn Time (sec)	Mean (SD) Median (IQR)	3.2 (2.1) 2.3 (1.8 – 4.3)	3.6 (3.2) 2.0 (1.8 – 4.8)
Turn Types	Incremental Pivotal Lateral	13 (59%) 02 (09%) 07 (32%)	15 (68%) 05 (23%) 02 (09%)
Turn Quality Score	Median (IQR)	4.5 (4 - 5)	4.0 (2.8 - 5)

There was an association between the Turn Types demonstrated under each condition (P = 0.049); 12 people (55%) demonstrated the same Turn Type in the DU Turn and DS Turn, while ten changed Type from the DU Turn to the DS Turn (**red** in **Table 7.3**). Nine people (41%) changed their movement-initiating foot from the DU Turn to the DS Turn. Similar proportions of those who maintained and changed Turn Type changed their movement-initiating foot (42% *v* 40%, respectively; FET, P = 1.000).

Table 7.3: DU Turn Types by DS Turn Types (n = 22)

		DS Turn Type			
		Incremental	Pivotal	Lateral	Total
DU Turn Type	Incremental	11	**1**	**1**	13
	Pivotal	-	1	**1**	2
	Lateral	**4**	**3**	-	7
	Total	15	5	2	22

Those who maintained Type tended to demonstrate *Incremental* Turns; they were of a similar age to those who changed Type (medians 72 *v* 67.5 years; P = 0.552) but had a shorter height-adjusted FR (medians 10.6% *v* 15.3%; P = 0.048). Those who maintained Type took more steps and longer to turn than those who changed. The overall number of Turning Steps taken by those who maintained Type was greater than that of those who changed (medians 4.8 *v* 3.5; P = 0.001), as was the overall Time (4.1s *v* 1.9s; P = 0.004).

Although the total Turn Quality Scores changed little from the DU to the DS Turn (**Table 7.2**, medians 4.5 *v* 4; P = 0.127) there were changes in the individual items. In **Table 7.4**, the five items constituting Turn Quality are presented in separate rows.

Table 7.4. Turn Quality Scores under DU and DS Conditions (n = 22)

	Same Rating on DU and DS Turn		**Different Rating on DU and DS Turn**	
Item	**Both = 1**	**Both = 0**	**DS = 0**	**DS = 1**
Posture	**17 / 22**	-	3 / 22	2 / 22
Stability	**15 / 22**	-	5 / 22	2 / 22
Continuity	**14 / 22**	2 / 22	5 / 22	1 / 22
Independence	**17 / 22**	4 / 22	1 / 22	-
Clearance	**13 / 22**	4 / 22	4 / 22	1 / 22

The columns show how many of the 22 participants were rated the same under the DU and DS conditions and how many were rated differently. Under the heading 'Same Rating', the participants who 'passed' and 'failed' the item are split. For example, with respect to 'Continuity', 16 participants achieved the same rating under both conditions; 14 turned continuously under both conditions, while two were discontinuous under both conditions. Under the heading 'Different Rating', the participants whose performance 'worsened' when the direction of turn was specified and those whose performance 'improved' are split. For example, with respect to 'Continuity', six participants achieved different ratings under the two conditions; five were rated as discontinuous only during the DS Turn and one who had demonstrated discontinuity turned continuously during the DS Turn. With the exception of the individuals who scored 1 under both conditions (highlighted in **green** in the table), the other participants scored zero during the DU and / or the DS Turn. That is, at some point during the SS-180, nine people failed to clear the ground with their feet, eight lacked continuity of movement, seven were unstable, five became more flexed as they turned, and five were unable to turn independently.

7.3.2 b The Correlates of Turning among People with PD

Table 7.5 shows the strength of the associations between the four aspects of the SS-180 measured during the DU Turn and the possible correlates outlined above; significant associations ($P < 0.05$) are highlighted in **bold** (see **Appendix 10** for illustrative graphs).

Table 7.5. Correlates of the DU Turn

Item	Value	Age (years)	Balance (FR% ht)	Duration (years)	UPDRS	SAS
Turning Steps	r_s	0.388	-0.335	0.129	0.181	0.585
	P	0.074	0.127	0.568	0.432	**0.004**
Turn Time	r_s	0.209	-0.533	-0.119	0.368	0.687
	P	0.350	**0.011**	0.597	0.100	**0.000**
Turn Type	P	**0.047**	0.131	0.855	0.490	0.171
Incremental (n=13)	Median	73	11%	9	21	61
Pivotal (n=2)	Median	52	17%	4	17	41
Lateral (n=7)	Median	68	13%	3	20	47
Turn Quality	r_s	-0.298	-0.066	0.027	-0.012	-0.284
	P	0.179	0.769	0.906	0.958	0.199

There were age differences among the participants who demonstrated different Turn Types; those who demonstrated Pivotal turns were younger than the others. Longer reach (better balance) was associated with turning faster. Disease Duration and Disease Severity as measured by the UPDRS were not associated with any aspect of the SS-180. The participants who rated themselves most severely disabled took the greatest number of steps and the longest time to turn.

Table 7.6 shows the strength of the associations between the four aspects of the SS-180 measured when the direction of turn was specified and the possible correlates outlined above; again, significant associations are in **bold** and illustrative graphs are included in **Appendix 10**. Neither Age nor Disease Duration was associated with any aspect of the SS-180. Longer reach (better balance) was associated with taking fewer steps and turning faster and demonstrating a Pivotal or Lateral Turn. More severe PD was associated with turning slower; those who demonstrated an Incremental Turn had more severe signs of PD than those who demonstrated a Pivotal Turn.

Greater self-assessed disability was associated with taking more steps and turning slower; those who demonstrated an Incremental Turn rated themselves more disabled than those who demonstrated a Pivotal Turn.

Table 7.6. Correlates of the DS Turn

Item	Value	Age (years)	Balance (FR%ht)	Duration (years)	UPDRS	SAS
Turning Steps	r_s	0.411	-0.635	0.027	0.355	0.731
	P	0.057	**0.001**	0.907	0.115	**0.000**
Turn Time	r_s	0.036	-0.499	-0.059	0.476	0.675
	P	0.874	**0.018**	0.794	**0.029**	**0.001**
Turn Type	P	0.583	**0.002**	0.563	**0.026**	**0.032**
Incremental (n=15)	Median	71	11%	3	24	61
Pivotal (n=5)	Median	67	16%	12	15	44
Lateral (n=2)	Median	66	20%	7	18	40
Turn Quality	r_s	-0.016	0.375	0.089	-0.225	-0.473
	P	0.942	0.085	0.694	0.326	**0.012**

Overall, as shown in **Table 7.7**, people who took the most Turning Steps were those with the worst balance control and who rated themselves as the most severely disabled. Those who turned slowest were those with the greatest disability, disease severity and worst balance control. None of the variables considered correlated with the change in Turn Quality Score but balance control came near. People with the shortest reach (worst balance) were most likely to achieve a lower score when asked to turn in a specific direction than the score that they achieved turning in the direction of their choice.

Table 7.7. Correlates of Overall Performance

Item	Value	Age (years)	Balance (FR% ht)	Duration (years)	UPDRS	SAS
Mean Steps	r_s	0.419	**-0.516**	0.087	0.278	**0.688**
	P	0.052	0.014	0.699	0.222	0.000
Mean Time	r_s	0.153	**-0.543**	-0.075	**0.459**	**0.705**
	P	0.498	0.009	0.740	0.036	0.000
Turn Quality Change	R_s	0.116	0.418	0.029	-0.227	-0.241
	P	0.609	0.053	0.899	0.322	0.279

7.3.3 How Controls Turned

7.3.3 a The DU and DS Turns

As shown in **Table 7.8**, the DU and DS Turns were completed in similar numbers of Turning Steps (medians both 3; P = 0.564) Turn Times (medians 1.7s *v* 1.6s; P = 0.256). With the exception of two people who paused before commencing straight forward gait (one during a DU Turn, one during a DS Turn), everyone scored 5 / 5 for Turn Quality.

Table 7.8. DU Turns and DS Turns: Ten Controls

SS-180 Item	Values	DU Turn	DS Turn
Turning Steps (n)	Mean (SD)	3.0 (0.5)	3.1 (0.9)
	Median (IQR)	3 (3 – 3)	3 (2.8 – 3.3)
Turn Time (sec)	Mean (SD)	1.7 (0.4)	1.6 (0.5)
	Median (IQR)	1.7 (1.4 – 2.0)	1.6 (1.3 – 1.7)
Turn Types	Incremental	1 (10%)	4 (40%)
	Pivotal	2 (20%)	1 (10%)
	Toward	1 (10%)	2 (20%)
	Lateral	6 (60%)	3 (30%)

Two people (20%) took more steps during the DS Turn (in comparison with their DU turn) and six (60%) turned faster. Six people (60%) changed movement-initiating foot from the DU to the DS Turn; they were less likely than those who maintained movement-initiating foot to change Turn Type (FET, P = 0.048, see **Table 7.9**). Five people (50%) demonstrated the same Turn Type under both conditions.

Table 7.9. Maintenance of Turn Type and Movement-initiating Foot (n = 10)

ID	DU Turn Type	DS Turn Type	Movement-Initiating Foot
1	Pivotal	Lateral	Same
3	Lateral	Toward	Same
6	Lateral	Incremental	Same
9	Lateral	Incremental	Same
10	Incremental	Incremental	Changed
2	Lateral	Incremental	Changed
4	Lateral	Lateral	Changed
8	Lateral	Lateral	Changed
5	Pivotal	Pivotal	Changed
7	Toward	Toward	Changed

7.3.3 b The Correlates of Turning among Controls

Tables 7.10 and **7.11** show the strength of the associations between the SS-180, age and balance control; significant associations ($P < 0.05$) are highlighted in **bold** (see **Appendix 10** for illustrative graphs). The only association identified was between age and Turning Steps when the direction of turning was specified; the older participants took more steps than did the younger participants.

Table 7.10. Correlates of the DU Turn

Item	Value	Age	Balance
Turning Steps	r_s	0.623	-0.547
	P	0.054	0.102
Turn Time	r_s	0.357	-0.411
	P	0.311	0.239
Turn Type	P	0.269	0.247
Incremental (n=1)	Median	89	9.2%
Pivotal (n=2)	Median	71	16.5%
Toward (n=1)	Median	59	21.2%
Lateral (n=6)	Median	69	20.1%

Table 7.11. Correlates of the DS Turn

Item	Value	Age	Balance
Turning Steps	r_s	0.720	-0.330
	P	**0.019**	0.352
Turn Time	r_s	0.512	-0.401
	P	0.130	0.251
Turn Type	P	0.422	0.747
Incremental (n=4)	Median	77.5	16.6%
Pivotal (n=1)	Median	65	20%
Toward (n=2)	Median	61.5	20.7%
Lateral (n=3)	Median	74	19.2%

When the overall performance of the SS-180 was considered, age correlated with the mean number of Turning Steps taken ($r_s = 0.731$ ($P = 0.016$); older Controls took more Steps than did younger Controls) but not with the mean Turn Time ($r_s = 0.456$, $P = 0.185$). Balance Control was not correlated with the mean number of Turning Steps ($r_s = -0.336$, $P = 0.343$) or the mean Turn Time ($r_s = -0.463$, $P = 0.177$).

7.3.4 Comparing People with and without PD

During the DU Turn, people with PD took more steps than the Controls (P = 0.007) and longer to complete the Turn (P = 0.010). The association between Type and Group was significant (P = 0.046). The proportions of each group maintaining Turn Type and movement-initiating foot were similar. The Turn Quality Scores of the people with PD and controls differed (P = 0.030). During the DS Turn, people with PD took more steps than the Controls (P = 0.029) and longer than the Controls to complete the Turn (P = 0.001). The association between Type and Group was significant (P = 0.049). The proportions of each group maintaining Turn Type and movement-initiating foot were similar. The difference in the Turn Quality Scores of the people with PD and controls was significant (P = 0.010). The differences between the mean Step Counts and mean Turn Times (**Table 7.12**) were also significant (P = 0.004 and P = 0.002).

Table 7.12. Overall Performance of the SS-180: People with and without PD

SS-180 Item	Values	People with PD (n = 22)	Controls (n = 10)
Mean Steps (n)	Mean (SD)	4.7 (2.4)	3.1 (0.6)
	Median (IQR)	3.8 (3.4 – 5.3)	3 (2.9 – 3.1)
Mean Time (sec)	Mean (SD)	3.3 (2.4)	1.7 (0.4)
	Median (IQR)	2.0 (1.8 – 4.5)	1.6 (1.4 – 1.8)
Turn Types	Incremental	28 (64%)	5 (25%)
	Pivotal	07 (16%)	3 (15%)
	Toward	0	3 (15%)
	Lateral	09 (20%)	9 (45%)
Turn Quality Change	Median (IQR)	0 (-1 - 0)	0 (0 - 0)

7.3.5 Responses to Questions on Falls and Turning

Turn-related Falls and Near-misses

Ten of the 14 repeat-fallers (71%) had fallen turning. Most had fallen turning indoors: crossing a landing, trying to turn right in front of a dressing table (one foot did not move), freezing in the hall, "in a tight spot", going "flying" attempting to turn right. One participant had landed on his hip twice after two turn-related falls and was "badly bruised". One teacher had "spun round" to write on a blackboard and fell. Two turn-related falls had taken place as the individual approached a chair to sit down.

One “had not turned enough” to sit safely in his chair. One was approaching a chair to sit down when, as often happened, her “mind switched to turning” and she fell; she encountered difficulty when she started to think about turning. Two turn-related falls that had taken place outdoors were described: one turning left, walking on the golf course and one in a garden “trying to turn left” and going “too far” without the feet moving, since when a garden fork has always been used for support.

Seventeen participants reported near-misses during the previous 12 months; nine (53%) highlighted turning as an activity associated with nearly falling. Becoming unstable during “sudden turns” was highlighted, e.g. turning quickly in the kitchen. Nearly falling when turning in confined spaces was described: e.g. turning in a very confined space in the kitchen, attempting to lay the table or having to make turns while in a queue. Two people singled out nearly falling when turning in particular directions; one woman described her feet not moving when she turned left. Three people described restoring their balance by grabbing something fixed or taking “two or three galloping strides”.

Exacerbation and Management of Dysfunction

Fifteen participants (65%) reported difficulty turning; six felt that their ability to turn was “gradually worsening”. One man froze when he thought of turning, another “stuck” having taken cutlery out of her sideboard and could not turn away; another tended to stick “halfway round”. Two people noticed difficulty turning just before their antiparkinsonian medication was due; one “shuffled”, one took “lots of little steps”. Conversely, another individual had difficulty turning only *after* the first dose of the day. Eight people found turning fast more difficult than turning slowly; one woman could not turn if she was “rushing”. Manoeuvring in confined spaces was frequently described as difficult. One man found turning in the toilet most difficult, as space was so restricted. One man tried to turn in a wide arc. One woman avoided corners and if stuck in one would have to “crawl” out of it. One woman tried not to turn more than was strictly necessary. Carrying anything while turning exacerbated three women’s difficulty. One man whose feet crossed as he turned found that thinking about anything else while turning exacerbated the difficulty. One man said that turning from a standing start was “the worst” type of turn so he tackled it “like an ‘about turn’ in the army”. One woman found turning away from a work surface difficult, as she had to step backwards: if she turned her head first, she managed the whole turn better.

The advanced planning of turning was a management strategy described by several participants. One participant tried to turn "ahead of" himself rather than sharply on the spot, one planned "intermediate movements" in advance of the turn "several moves ahead", one prepared "in advance" to negotiate corners and turned taking a wide path and one preferred to "carry on walking" rather than swivel. Four people found turning right "slightly easier" than turning left, so tended to turn in the preferred direction whenever possible. Three people used a walking stick to help themselves turn safely, three described how they made a point of turning in stages and one man held on and concentrated on maintaining his posture. Four instances of difficulty turning *beyond walking* were described; two in relation to taking corners while driving, one in relation to swimming and one in relation to dancing. One woman found cornering in her car more disjointed than it had been; she would drive up to a corner, break and then turn the corner in three distinct phases: another woman said she took corners as if she had just learned to drive. When reaching the end of a length of the swimming pool, one man had started to experience movement difficulties just prior to making his turn. Because she could no longer turn, one woman had had to give up dancing.

7.3.6 Summary of Findings

Twenty-three people with PD were recruited (22 attempted the SS-180); median age was 68, median time since diagnosis was four years. Most were at Hoehn and Yahr Grade III. Two-thirds reported difficulty turning; turning quickly, in a confined space or without time to plan were frequently reported to exacerbate the difficulty. Nearly three-quarters of the repeat-fallers had fallen turning and half of the participants who reported near-misses highlighted turning as an activity that they associated with nearly falling. Advanced planning, moving in a preferred direction and breaking the task down into distinct phases were among the most common management strategies described. Ten controls were recruited for comparison; median age was 69.5.

<u>How People Turned during the SS-180</u>

People with PD performed the DU Turn in a median of four Steps in a median 2.3s: the Controls turned in fewer steps and faster. More than half of the PD Group demonstrated an Incremental Turn; a different distribution of Turn Types was seen in the Control Group. People with PD scored lower than the Controls for Turn Quality.

People with PD performed the DS Turn in a median of four Steps in a median 2.0s: the Controls turned in fewer steps and faster. More than two-thirds of the PD Group demonstrated an Incremental Turn; a different distribution of Turn Types was seen in the Control Group. People with PD scored lower than the Controls for Turn Quality.

Overall Performance of the SS-180 reflected the mean number of steps and time taken to turn in each direction, the overall frequency of Turn Types and the change in Turn Quality from the DU to the DS Turn. People with PD took significantly more steps than the Controls (the group mean was 50% higher) and turned more slowly (the PD Group mean was twice that of the Controls). Incremental Turns were the most prevalent Type in the PD Group, whereas Lateral Turns accounted for almost half of the turns demonstrated by Controls. Neither group showed much change in Turn Quality.

The PD Group performed their DU and DS Turns in similar numbers of steps and in similar times and achieved similar Turn Quality Scores. Most demonstrated the same Turn Type in both directions. The DU and DS Turns of the Controls were also similar.

Correlates of Turning

In the PD Group, of the five factors considered (age, balance, time since diagnosis, the UPDRS and the SAS), self-assessed disability was the closest correlate of the number of steps and time taken to turn in a freely chosen direction (better balance, too, correlated with turning more quickly). Age was the only factor to differ significantly among the participants demonstrating different Turn Types: Pivotal Turners were a median 20 years younger than the Incremental Turners. None of the factors correlated with Turn Quality. When the direction of turning was not that chosen freely (i.e. the DS Turn), those with less severe disease and better balance took fewer Turning Steps and a shorter Turn Time than those with more severe disease and more impaired balance control and demonstrated different Turn Types. Those with more self-assessed disability scored lower for Turn Quality than those who rated themselves as less severely disabled.

In the Control Group, age and balance control were considered as possible correlates of turning. Older Controls tended to take more Steps than did the younger Controls.

7.4 Discussion

The SS-180 had already proved to be a suitable tool with which to measure turning in the laboratory; it provided a valid and reliable description of how people turned from a standing start and was quick and easy to conduct without adverse incident. The first part of this discussion addresses issues pertaining to conducting the SS-180 in a different setting, the home environment. The second part of the discussion then focuses on the study findings and what they add to the earlier laboratory-based investigations, the limitations of the work completed and directions for continuing research.

7.4.1 Movement Analysis in the Home

This investigation successfully overcame some of the sample limitations in the laboratory-based studies discussed in the preceding chapters.

1. The convenience sample of controls who participated in the *Healthy Adult Study* was criticised in Chapter Five for being to some extent familiar with research and in that respect rather select. This criticism can not be levelled at the controls in the current study.
2. The sample of healthy adults studied in the laboratory was of a very different age structure to the expected samples of people with PD studied in the laboratory and at home. During this investigation, much older controls were recruited, a group of a very similar age structure to the participants with PD with who they were compared.
3. No participant in the *PD Laboratory Study* had been diagnosed any more recently than 1995, i.e. seven years earlier. In this investigation, the median time since diagnosis was just four years and 13 participants 57% had been diagnosed between one and four years.

The response of the PD Society branch approached was very positive. Members were interested in research in general and very willing to participate in this project and any future projects stemming from the findings. There were many advantages in recruiting people via the branch, advantages that were apparent when people were visited at home.

Potential participants knew that the Branch Chair and Secretary had discussed and approved the project, which allayed some of the anxieties they may have had. Members often had friends and social contacts within the branch and word quickly spread between them after one had participated, encouraging others to do the same. The fact that people had joined a group like a local branch of the PD Society meant that many were interested in PD research and keen to meet the researcher and share information.

Such an interested and enthusiastic group could be easily exploited. The advantages outlined above could have made the participants vulnerable to an unscrupulous researcher. For example, the fact that branch officials had approved the project could have been used to sway individuals who were unsure whether they wanted to participate. Encouragement from other participants could have left some individuals feeling obliged to take part. Furthermore, because people were so in favour of research being undertaken to advance the diagnosis, management and prevention of the condition, they could have felt obliged to participate. The researcher was alert to these possibilities throughout the project and, in order to ensure that no one felt coerced into taking part, was explicit about these risks when securing consent. As people were so helpful and interested and so willing to contribute in the future, an ongoing link with the group was established; the researcher was invited to join the branch and did so. Discussing future research proposals during their development with members of the branch would be one way of involving people with PD in a positive way, without exploiting their good will, while ensuring that people are not burdened with frequent requests to participate in studies.

The people who participated in the current investigation constituted a varied sample: they ranged in age from 46 to 84 and those with PD had been diagnosed between one and 25 years. With the exception of one participant with severe PD, everyone was able to attempt the SS-180. As in the laboratory, the protocol worked well; people understood the instructions and demonstrated what was expected of them. The requirement for space to perform the test was met in every home, so every video record could be analysed. Similarly, it was always possible to find a place in which to conduct the FR Test safely. Carrying out this type of movement analysis in the home was successful and the method could be repeated without amendment.

However, as in the laboratory, the SS-180 challenged a number of participants in the PD Group. At some point during the test:

- One quarter needed assistance (a walking stick or support from the researcher)
- One third appeared unstable, and
- Just under half failed to clear the floor with their feet.

So many people with PD appeared at risk of falling as they performed the test unhindered, that only eight were asked to repeat the SS-180 for the sub-study discussed in Chapter Eight. There was enough evidence to suggest that this test was challenging for a significant proportion of people with PD and should only be attempted when the risk to the participant had been assessed. This is discussed further in Chapter Nine.

In the home, it was not possible to measure the magnitude of individual *Turning Steps* or *Progress to the Target* from video but it was still possible to identify participants turning 'on-the-spot'. An Incremental Turn implies that the turner re-orientates to the target prior to straight forward gait. Significantly more of the turns demonstrated by people with PD were of this Type than those demonstrated by the controls (64% *v* 25%).

7.4.2 The Findings

As Incremental Turns were seen so often, it appeared that breaking down a standing-start turn into its rotational and straight forward components was a common adaptation demonstrated by people with PD. Imms and Edholm (1981) considered discontinuity between turning and walking a 'fault': whilst such discontinuity may reflect difficulty turning, it is perhaps one way of making the manoeuvre more manageable. Incremental Turns were more frequently observed among the controls in this investigation than among the participants in the *Healthy Adult Study*; 25% of turns *v* 5%, respectively. The difference in the ages of the participants may explain this finding; with increasing age people were more likely to turn 'on-the-spot' before walking forward. A longitudinal study would be required to test this hypothesis, as it was possible that the controls in the current investigation had always turned Incrementally. Despite some overlap in the Turn Types demonstrated by people with PD and healthy elderly people, the interviews confirmed other research that showed dysfunctional turning to be a serious and common motor deficit *in PD* (e.g. Bloem et al, 2001; Nieuwboer et al, 1998; Giladi et al, 1992).

On every section of the SS-180, the participants with and without PD differed significantly, raising the possibility that the test could be useful in the diagnosis of PD. Further work would be required confirm whether or not a measurable difference exists between people with early PD and age-matched controls: the researcher analysing the SS-180 would have to be blind to diagnosis. As discussed in Chapter Nine, data gathered during this project could be used to propose a predictive model for future testing.

The results obtained in this investigation were in keeping with those of the earlier laboratory-based studies. The median Turning Steps of the controls seen at home and in the laboratory differed by half a step and the former demonstrated more Lateral Turns than the laboratory sample (who demonstrated more Toward Turns). As the sample seen at home was the older sample, these slight differences were in the direction anticipated, in light of the findings of Cao et al (1997 and 1998). The people with PD seen at home took more Turning Steps than the laboratory sample (medians 6 and 3.8, respectively) and the former took longer to turn. Again, the differences were in the direction anticipated; the laboratory sample was older, longer diagnosed longer, with more severe PD and a shorter height-adjusted FR, in light of the findings of Simpson et al (2002).

Dysfunctional turning (loss of continuity and / or stability when attempting to turn) reflected balance impairment. Evidence came from the finding that balance control, reflected by height-adjusted FR, correlated negatively with the time taken to turn by people with PD; the shorter the reach the longer the Turn Time. Moving slowly may have been a strategy adopted in recognition of instability during turning though alternatively it may have been a compensation for a general fear of falling. The correlation between performance and fear of falling was not explored in this study but the effect of this possibly confounding variable has concerned other researchers (e.g. Maki et al, 1997; Vellas et al, 1997). Other possibly confounding variables not yet explored include drug use, falls and co-existing pathologies (e.g. joint disease, visual impairment). These must be considered limitations of the work undertaken and could all be usefully explored in further studies.

The participants with PD had a significantly shorter height-adjusted FR than the Controls (medians 12% *v* 20%). Being a cross-sectional study, it was impossible to know whether the people with PD had always had poor balance or whether their control had deteriorated over the disease course. Either way, the differences in the group performances of the SS-180 appeared to reflect reasonable compensation as the PD Group tackled this challenge to their postural stability. As balance control deteriorates, taking an increasing number of increasingly small steps would be an appropriate modification to turning 180° (as also suggested by Morris et al 2001).

However, taking so many steps increases the possibility of a fall-provocative error during any one step. People with PD who habitually fall turning may be caught in a no-win situation. The compensation that they deploy in response to postural instability increases the number of movements that they are required to instigate, control and terminate, which increases the chance of one step 'failing', e.g. freezing or tripping. When a step in the sequence fails, the turner may be unable to save themselves from falling because of their impaired saving reactions (Bloem et al, 2001; Stack and Ashburn, 1999); literally a vicious circle. Therapeutically, encouraging people with PD to turn even more slowly may be useful. Taking the time to perform each individual step safely might prevent the turner from thinking too far ahead. Some of the participants interviewed suggested that thinking about turning was enough to induce problems; thinking one step at a time might be less challenging than trying to plan the whole manoeuvre.

As turning from a standing start correlated so closely with balance control, working on balance might also be useful therapeutically when people complain of difficulty turning.

The correlation between the SAS and the SS-180 suggested that people with difficulty turning from a standing-start considered themselves hindered in a range of activities. To people without PD, a standing start turn appears easily accomplished; when an individual finds such a manoeuvre problematic it is hardly surprising that other activities are an effort. The SS-180 may have the potential to serve as a simple indicator of activity level. Further studies would be needed to establish whether the ability to turn is a useful way of identifying individuals who could benefit from a therapist's advice.

The finding that disease duration was not correlated with any section of the SS-180 was surprising and raises a number of possibilities:

- Dysfunctional turning may not worsen as the disease progresses. Some of the most recently diagnosed individuals had the most difficulty turning.

- Only certain presentations of PD may be accompanied by dysfunctional turning. People either have difficulty turning or quite different signs and symptoms.

- Defining disease duration as the time since diagnosis may hide an association between duration and dysfunctional turning. The definition was chosen because the date of diagnosis is memorable; trying to recall when symptoms were first evident (as people with PD may try to do retrospectively) would seem less memorable. However, the definition was limited because a) people wait different times before seeing their GPs with symptoms, b) the times taken by the GPs to refer on vary and c) the times between referral, consultation and diagnosis also vary widely.

Longitudinal research on the ability to turn at and around the time of diagnosis would be interesting. There may be individuals who notice increasing difficulty turning but would not think to mention it to a health care professional because they attach to it no significance. It may be a very useful symptom for which to probe.

As well as being an age-matched Control Group for comparison with the PD Group, the healthy adults added to the emerging picture of how people without PD turn. The findings were in keeping with those of the laboratory-based *Healthy Adult Study*: the correlations between age and Section One of the SS-180 were of similar strengths and the lack of statistical significance in the current investigation can be attributed to sample size. In Chapter Nine, the findings from both studies are considered as a whole. The only correlation identified in the current investigation was between Turn Type in a freely chosen direction and age; older controls tended to demonstrate Incremental turns. Further studies would require age-matched controls because people of different age turn differently. As expected, in the presence of PD, the association between age and turning become insignificant (even balance control no longer correlated with age).

A greater proportion of the Control Group than the PD Group changed movement-initiating foot from the DU to the DS Turn. It may be that healthy adults were able to take an effective initial step with either foot whereas people with PD favoured one side when initiating movement. This may be why people with PD notice particular difficulty turning in one direction; whilst healthy adults can instigate an effective manoeuvre in either direction, people with PD try to initiate turning in the same way regardless of the direction in which they are trying to turn. Therapeutically, it may be beneficial to explore whether turning is easier when started with a particular foot.

7.5 Conclusions

The SS-180 can be conducted in the home but with caution: it was challenging for many of the participants with PD. Difficulty turning was reported by two-thirds of the people with PD recruited. Most took five steps to turn, in three seconds, turning on-the-spot. Most (17/22) were independent turning both ways and maintained their postural extension as they did so; fewer were stable throughout, fewer still moved continuously throughout and even fewer cleared the floor with their feet as they completed a turn in each direction.

Disease severity, particularly self-assessed disability, was closely associated with the performance of the SS-180 but disease duration appeared unconnected. Most controls took three steps to turn, in two seconds, mostly demonstrating Lateral Turns: two paused after turning before walking toward the target but otherwise there was no indication of any difficulty. Among this sample, age correlated with the Turning Steps taken.

People with and without PD completed the SS-180 significantly differently. The performances of the people with PD may reflect appropriate compensations for their impaired balance control, though taking multiple steps on the spot could put people at risk of falling should they freeze or trip during any step. Working on balance control and encouraging slow stepping, thought through one step at a time and initiated with the most stability enhancing initial Turning Step are therapeutic interventions that might make people with PD able to turn with less difficulty.

This investigation (with those in the laboratory) has revealed how people with and without PD perform standing start turns. What happens to the ability of someone with PD to turn when additionally stressed (i.e. turning in their non-preferred direction or turning when carrying something) is explored in the following chapter. It begins with a discussion of the interviews conducted with people with PD, in which they described dysfunctional turning and what they had found to exacerbate their problems.

Chapter Eight

Deterioration in the Ability of People with Parkinson's Disease to Turn when Placed under Additional Stress

8.1 Introduction and Overview

Building on the studies reported in Chapters Five to Seven, two analyses were undertaken to explore some of the factors thought to exacerbate the dysfunctional turning that is associated with PD. The studies discussed in this chapter are:

1) The interviews in which people with PD described their turning difficulties, and
2) A comparison of turns in each direction.

The chapter opens (Section 8.2) with a discussion of the interviews conducted with the 30 people with PD who participated in the laboratory-based and home-based studies. The reasons for conducting the interviews were:

1) To learn from people with PD what exacerbated their turning difficulties and how they dealt with the difficulties that they were experiencing.
2) To gain an insight into the prevalence of dysfunctional turning among the sample.
3) To identify individuals at particular risk of falling when turning

One factor that can exacerbate the difficulty of turning is the necessity of having to turn *in a particular direction.* The exploration of difficulty-exacerbating factors continues by testing the null hypothesis that people with PD turn similarly in both directions (Section 8.3) and asking whether an individual at risk of dysfunctional turning *when direction is imposed* can be identified from the way they performed a DU Turn (Section 8.4).

8.2 Dysfunctional Turning as described by People with PD in Structured Interviews

When planning the interviews, it was envisaged that the insights gained would be useful in formulating further research questions and suggesting avenues for therapeutic intervention. People with difficulty turning might have avoided participating in the study so it was useful to find out whether the participants had experienced adverse outcomes when attempting to turn round. In the case of anyone reporting a problem, as much attention as possible could be paid to his or her safety when they undertook the SS-180.

The thirty participants with PD who took part in the studies outlined in Chapters Six and Seven were asked about falls and turning *prior* to undertaking the SS-180. The questions were outlined Sections 6.2 and 7.2 to clarify how they fitted into the data collection procedure and the responses were presented in Sections 6.3 and 7.3. The findings have been combined here as they fit best within the remit of this chapter. The discussion is focused under the headings, *Turn-related Fall-events*, *Factors Found to Exacerbate Difficulty Turning* and *The Self-management of Dysfunctional Turning.* The participants' responses are summarised (in a box) under each heading.

8.2.1 Turn-related Fall-events

- Seventy-two *percent* of the repeat-fallers had fallen while turning.
- Most falls were indoors, e.g. bedroom, kitchen and bathroom, crossing a landing, freezing in the hall, "in a tight spot", approaching a chair.
- Twelve participants (40%, both fallers and non-fallers) highlighted turning as an activity during which they had nearly fallen, e.g. feet not moving as anticipated or instability at speed.

Despite the possibility that people who had experienced difficulty turning would be reluctant to participate in a study in which turning was the focus a significant proportion of the individuals recruited described day to day difficulties when attempting to turn. When debating the value of research into one very specific manoeuvre, it is worth emphasising that three-quarters of the participants who fell repeatedly had done so turning. This finding adds to our previous research, which had highlighted the prominence of turning among the activities most commonly associated with falls in PD. Repeat-fallers are at high risk of serious fall-related injury and likely to continue experiencing falls, in some cases until diminishing independent mobility limits their opportunity to fall. With turning such a prominent cause of falls among this high-risk group, it is worth trying to develop some very specific fall-preventive interventions.

The majority of all falls occur indoors, particularly among frail individuals. These interviews have highlighted the myriad situations in which people had fallen turning in their own homes, in contrast to the rare occasions on which turning was associated with an outdoor fall. This leads one to speculate that the physical environment could be contributing to turn-related falls, in as much as negotiating a path through the home environment could necessitate numerous tight turns, unnecessary outdoors. The occasions when it is necessary to turn at least 90° (and often 180°) during the day, within the confines of one room, are numerous and the participants in this study highlighted a number of examples. The smaller rooms (e.g. bathrooms and kitchens) featured in many descriptions of fall-events during turning, with the participants being explicit about the difficulty.

Whether or not modifying the domestic environment (so that the need to turn in a confined space is minimised) reduces the frequency of fall-events would be worth exploring in a future study. Quite *how* an individual with PD attempts to turn in a confined space (and why attempting to do so might lead to a fall) remains to be established but, again, would be worth exploring in a future study; the exacerbating factors highlighted below raise a number of possibilities.

8.2.2 Factors Exacerbating Difficulty Turning

- Twelve people found turning *quickly* especially problematic.
- Turning in a *confined space* (e.g. the toilet, a tight corner or away from a work surface) was frequently described as difficult.
- Turning while *carrying* anything exacerbated four people's problems.
- Twenty-one (70%) of the participants reported difficulties turning: one froze just *thinking* about it.
- Three described disjointed turning when *driving and swimming.*
- Three noticed more difficulty just before or after antiparkinsonian *medicatio*n.

To a large extent, the first three factors highlighted above (moving fast without broadening one's base or holding a fixed support) would challenge the ability to move safely of anyone with any kind of balance disorder. For a therapist, advising a patient complaining of difficulty turning that his or her risk of falling could be increased if these factors were not borne in mind could be a simple first-line intervention. Three of the issues raised were, however, much more specific to people with PD: freezing when thinking about turning, difficulty turning during activities that did not demand high level balance control and difficulty related to the timing of medication.

Several of the participants reported freezing when intending to turn (in all, three-quarters had found turning difficult in some respect). Interestingly, one participant described freezing that occurred without actually attempting to turn but when only thinking about turning. This suggests that the difficulty people with PD have when turning can not be attributed solely to physical impairments, such as those affecting balance control: dysfunctional turning appears to have a cognitive component. The people who described difficulties turning when driving or swimming further support this assertion: they recounted difficulty as they *approached* the point where they would have to make a turn. It seems as though people who have physical difficulty turning are being further hindered by their conscious awareness of the difficulty. As the need to turn arises, they become aware of the need to perform the requisite sequence of movements but in attending to that sequence they freeze in the middle of their current motor task.

From a research perspective, it would be interesting to compare the physical changes that occur in people with and without PD as they *perceive the need* to turn, prior to beginning the turn (e.g. changes in axial muscle activity or brain activity). The possibility of measuring such changes in a subject seated at a driving simulator, for example, could overcome the challenge of measuring them in an ambulant subject. The suggestion that for some individuals the ability to turn fluctuates with the timing of their antiparkinsonian medication leads one to suspect that the dopaminergic pathways are involved in the performance of turning. Having a sample of people with PD repeat the SS-180 at different points between doses could test this hypothesis.

From a therapeutic perspective, it would be useful to know whether it is the physical or the cognitive component of dysfunctional turning that fluctuates with the level of available dopamine (if indeed it is either). It would be interesting to explore the value of a cognitive strategy for negotiating turns for those individuals who experience dysfunction prior to beginning the manoeuvre. An analogy for this approach would be to consider a strategy golfers use to avoid sand and water hazards. Rather than focus their attention on (avoiding) the hazard, they visualise their route to the green without the hazard there and try to imagine all that lies between them and their target as hazard-free fairway. They make explicit their desire to "go to the green" and consciously attend to that, rather than to "stay out of the hazard". If people with PD prone to freezing prior to turning could learn to attend to their target rather than dwell on the intervening hazard (i.e. turning), they might find their movement less disturbed. Yekutiel (1993) reported the experience of a similar intervention.

All of the difficulty-exacerbating factors highlighted here should be warning signs for researchers interested in how people with PD turn. The manoeuvre is challenging enough; superimposing these additional stresses could lead to a loss of stability. In the final part of this discussion, I consider how people who have difficulty turning manage the potential loss of stability.

8.2.3 Self-management of Dysfunctional Turning

- Several avoided "dramatic" direction changes, planning turns "in advance".
- Five preferred to turn in the direction that they knew to be easier.
- Three consciously turned in stages; i.e. stop walking, turn, resume walking.
- Three used a walking stick to help themselves turn safely, one held on and concentrated on his posture and another found that thinking about anything else while turning exacerbated his difficulty.

Having suggested above that, for some people, difficulty turning arises at the planning stage, it is appropriate to begin by discussing the safety-enhancing value of prior planning. Planned safety-enhancing strategies would appear to include a) smoothing the planned trajectory, b) choosing direction and c) breaking down the task ahead.

Several participants tried to avoid dramatic changes in direction, planning a course around obstacles that minimized the need for deviation from the straight forward path. This 'avoidance' strategy minimized the need to tackle acutely angled turns at high speed. Following a slightly curved path might be a useful strategy because if it is less physically demanding (e.g. of balance control and range of movement) than a tight turn or if, at a cognitive level, it minimizes the need to turn (replacing turning with a slightly deviant straight forward gait).

Why turning seem easier in one direction than another is difficult to explain. During straight forward gait, the lower limbs alternately perform the same sequence of events but during turning the lower limbs move differently to each other. It might be that the movement sequence required is easier in one direction than the other because one lower limb is better able to meet the demands placed on it. Take for example, a healthy woman turning left from a standing start using a Toward Type Turn. During the first Turning Step, she transfers her weight right and moves her left foot towards the target, externally rotating her hip, so that when her foot is replaced on the ground it is aligned only a few degrees short of the path along which she will walk.

Her left foot may strike the ground flat or even toes-first; the left leg rapidly becomes the supporting limb over which she maintains her balance as the right leg sweeps through a wide arc of 180° during the second Turning Step. As her right heel strikes the ground her left leg begins to resume rotation external rotation so that at toe-off (as straight forward gait begins) both feet are aligned toward her target. The demands during each step are quite different and might explain why turning can be asymmetrically difficult.

In this example, turn initiation involved weight-transfer right; this could be hindered by lack of mobility in the trunk or around the hips. The left hip externally rotated and the right hip internally rotated to accomplish the 180° change in the alignment of the feet. The range of available rotation of the hips (passive or active) might be a factor in making movement in one direction difficult. The left foot struck the ground in a less stable position than it would have done during straight forward gait, i.e. not heel-first. Instability around the ankle might dictate towards which direction turning was easier. The left leg then became the stance leg for a relatively long second step. If one had particularly poor balance on one lower limb it would not be the stance limb of choice during a long swing phase.

The contributions of both lower limbs are clearly different in the healthy adult who turns in two steps. There would still be differences in lower limb movements during a multiple-stepping turn, such as the Incremental Type common in PD. For example, one hip rotates externally while the other rotates internally. The focus of the measurement of turning in this thesis has been predominantly the feet, i.e. the magnitudes and patterns of Turning Steps. However, movement higher up (e.g. rotation of the cervical spine) may be asymmetrically impaired and contribute to particular difficulty turning in one direction. If an individual has greater rotation available in one direction, he or she may prefer to turn that way so that they can achieve an earlier visual fix on their target. A therapist could encourage an individual with PD having difficulty turning to find out in which direction turning was safer for them. Difficulty turning in a particular direction might indicate a unilateral weakness or stiffness that might be amenable to intervention.

Clearly, a number of approaches have been found useful in managing the difficulty associated with turning. The third strategy described by the participants was breaking down turning into component parts, a strategy that therapists working with people with PD could easily promote. This strategy, in which each part of the maneuver is consciously tackled in sequence, appears in some ways contradictory to the approach suggested above, in which the *target* was the focus, *not the turn.* An individual who finds turning problematic and has not found a solution would require a therapist to listen carefully, observe him or her turning and identify the most appropriate safety-enhancing strategy from the many possibilities. The other strategies described by the participants in this study were more general approaches to promoting safe movement but again showed the split between physical and cognitive measures. For people with poor balance, using walking aids or secure handholds whilst turning seems appropriate whilst for those easily distracted by extraneous stimuli, sole concentration on turning safely should be emphasised.

8.2.4 Summary and Conclusion

While dysfunctional turning is evidently a very common problem for many people with PD, there would appear to be a number of strategies that promote the safe accomplishment of this necessary aspect of functional mobility. Therapists should explore whether patients have difficulty turning because of their physical impairments or because they lack a way of overcoming the cognitive challenges of turning.

8.3 Do People Turn Similarly Both Ways?

People with PD may show decrements in their ability to turn when compelled to turn in the direction that they found most challenging, whereas others may be better able to turn round when externally cued to do so. In the latter case the *explicit instruction* to turn left or turn right might bring into play parts of the brain that control volitional movement. In the studies outlined in Chapters Six and Seven, the *groups* had performed DU Turns in the same way as they performed DS Turns but, within the groups, some individuals turned faster when direction was imposed whereas others slowed down, for example. The question arises, is the SS-180 performed differently when the direction is freely chosen (i.e. a DU Turn) or imposed (i.e. a DS Turn), both in the case of people with and without PD? A *reported* discrepancy in turning both ways might not be reflected by an actual performance difference. The null-hypothesis tested was that there was no difference between the way people turned in both directions. If people *without* PD turned similarly in both directions, a directional asymmetry in the turns of people *with* PD could have use in supporting a diagnosis.

8.3.1 Methods

No additional testing was required to investigate the effect of direction on the performance of turning, because the SS-180 incorporates one turn in each direction. The DU Turns and DS Turns of every participant in the studies outlined in Chapters Five to Seven were compared, i.e. 29 people with PD tested in the laboratory and at home and 41 healthy adults tested in the laboratory and at home. The characteristics of the participants are summarized below. The performances of the DU and DS Turns were summarized and compared. Turning Steps, Turn Times and the Turn Quality Scores were compared using the method recommended by Altman to delineate the 95% Limits of Agreement (detailed previously in Section 4.3.1). The Wilcoxon Test was used to test the difference between the DU Turns and DS Turns. Turn Types demonstrated during the DU Turns and DS Turns were compared using the Chi-Square Test.

8.3.2 Results

The participants with PD ranged in age from 46 to 85 years (median 70, IQR 63 - 77) and disease duration from one to 25 years (median seven, IQR 3 - 13). Two were at Hoehn and Yahr Grade II, 23 at Grade III and five at Grade IV. UPDRS Scores ranged from five to 38 (median 21, IQR 15 - 27) and SAS Scores from 30 to 88 (median 56, IQR 44 - 67). Height-adjusted FR ranged from 5% to 21% (median 11%, IQR 8% – 15%). In comparison, the healthy adults were younger (range 21 – 89, median 44, IQR 35 - 61) and had a longer height-adjusted FR (range 9% – 26%, median 20%, IQR 17% - 21%).

Turning Steps

People with PD:
The median number of Steps taken in the DU Turn and in the DS Turn was 4 (P = 0.960). Eleven people (38%) took more steps when direction was imposed, 11 took fewer (38%) and seven took the same number of steps in both directions (24%, see **Table 8.1**).

Table 8.1 Differences in Turning Steps from the DU to the DS Turn: PD

Difference in Turning Steps from the DU to DS Turns	Number of Participants	Cumulative Total
0	7 (24%)	
1	14 (48%)	21 (72%)
2	3 (10%)	24 (82%)
3	1 (3%)	25 (85%)
4	2 (7%)	27 (92%)
5 +	2 (7%)	29 (99%)
	29 (100%)	

Excluding one outlier (with a difference of 13 Turning Steps), the mean difference between the Turning Steps taken in each direction was 0.2 (SD 1.9). The 95% limits of agreement ran from –4.1 to 3.7. Including the outlier value gave increased the mean difference to 0.3 (SD 3.1) with 95% limits from –5.9 to 6.5.

Healthy Adults:

The median number of Turning Steps taken in the DU Turn and in the DS Turn was 3 (P = 0.248). Eight people (20%) took more steps when direction was imposed, four took fewer (10%) and 29 took the same number of steps in both directions (71%, **Table 8.2**).

Table 8.2. Differences in Steps from the DU to the DS Turn: Healthy Adults

Difference in Turning Steps from the DU to DS Turns	Number of Participants	Cumulative Total
0	29 (71%)	
1	12 (29%)	41 (100%)
	41 (100%)	

The mean difference between the Turning Steps taken in each direction was 0.1 (SD 0.5). The 95% limits of agreement ran from –0.9 to 1.1.

Turn Times

People with PD:

The median Turn Time taken in the DU Turn was 2.5s and in the DS Turn was 2.3s (P = 0.493). Thirteen people (45%) took longer to turn when direction was imposed, 14 turned faster (48%) and two were timed identically in both directions (7%).

Table 8.3 Differences in Turn Times from the DU to the DS Turn: People with PD

Difference in Turn Times from the DU to DS Turns	Number of Participants	Cumulative Total
< 1s	22 (76%)	
1 – 1.9s	3 (10%)	25 (86%)
2 – 2.9s	1 (3%)	26 (89%)
3 – 3.9s	2 (7%)	28 (96%)
4s +	1 (3%)	29 (99%)
	29 (100%)	

Excluding one outlier (with a difference of 8.2s), the mean difference between the Turn Times taken in each direction was 0.1s (SD 1.2s). The 95% limits of agreement ran from –2.3s to 2.5s. Including the one extreme value gave a mean difference of 0.4s (SD 1.9) with 95% limits from –3.4s to 4.2s.

Healthy Adults:

The median Turn Time taken in the DU Turn was 1.5s and in the DS Turn was 1.6s (P = 0.816). Seventeen people (41%) took longer to turn when direction was imposed, 17 turned faster (41%) and seven were timed identically in both directions (17%).

Table 8.4. Differences in Turn Times from the DU to the DS Turn: Healthy Adults

Difference in Turn Times from the DU to DS Turns	Number of Participants	Cumulative Total
≤ 1.0s	41 (100%)	
	41 (100%)	

The mean difference between the Turn Times taken in each direction was 0.03s (SD 0.4). The 95% limits of agreement ran from –0.4 to 0.4.

__Turn Types__

People with PD

The same Turn Type was demonstrated by 17 of the 29 participants (59%, **blue** in the table) when they turned both ways (Chi Square; P = 0.002).

Table 8.5. Turn Types in the DU and DS Turns: People with PD

		DS Turn Type				
		Delayed	**Incremental**	**Pivotal**	**Lateral**	**TOTAL**
DU Turn Type	**Delayed**	**1**				**1**
	Incremental	1	**15**	1	1	**18**
	Pivotal			**1**	1	**2**
	Lateral		5	3		**8**
	TOTAL	**2**	**20**	**5**	**2**	**29**

Healthy Adults:

The same Turn Type was maintained by 26 of the 41 participants (63%, **blue** in the table); Chi Square, P = 0.000.

Table 8.6. Turn Types in the DU and DS Turns: Healthy Adults

		DS Turn Type				
		Incremental	**Pivotal**	**Toward**	**Lateral**	***TOTAL***
	Incremental	2			1	***3***
DU	**Pivotal**		8		1	***9***
Turn	**Toward**		3	9	1	***13***
Type	**Lateral**	3	3	3	7	***16***
	TOTAL	***5***	***14***	***12***	***10***	***41***

Turn Quality

People with PD:

The median Turn Quality Score in the DU Turn and in the DS Turn was 4 (P = 0.155). Ten people (34%) achieved a lower Quality Score when direction was imposed, seven a higher Score (24%) and 12 the same Score in both directions (41%). The mean difference between the Turn Quality Scores in each direction was 0.4 (SD 1.5). The 95% limits of agreement ran from –3.4 to 2.6.

Table 8.7. Differences in Turn Quality from the DU to the DS Turn: People with PD

Difference in Turn Quality Scores from DU to DS Turn	Number of Participants	Cumulative Total
0	12 (41%)	
1	09 (31%)	21 (72%)
2	03 (10%)	24 (82%)
3	04 (14%)	28 (96%)
4	01 (03%)	29 (99%)
	29 (100%)	

As the Turn Quality Scores of the Healthy Adults were almost without exception maximal (i.e. 5/5), further analysis was inappropriate.

8.3.3 Discussion

There were apparent differences in performance when turns in different directions were compared but the differences would not have been apparent when the groups as a whole were considered. Only one quarter of the PD Group took the same number of steps in both directions and only two people were timed identically in both directions.

Turn Type and Quality showed more consistency when turns in both directions were compared. People *without* PD tended to turn similarly in both directions. Nearly three-quarters took the same number of steps in both directions, seven were timed identically both ways and two-thirds demonstrated the same Turn Type under both conditions.

Considering the 70 participants with and without PD as a whole, 24 (34%) demonstrated a Lateral turn when they turned in the direction of their choice, of whom only seven (all healthy adults) demonstrated the same Type when compelled to turn in the other direction. This was the most common change in Turn Type associated with a change in the direction of turning.

These findings suggest that asymmetry in the turns of people with PD might have some use in supporting a diagnosis. No healthy adult demonstrated a difference greater than one step turning in both directions; in contrast, 28% of those with PD demonstrated a difference of two or more steps. Perhaps a difference of two or more steps could be a feature of the SS-180 that could support a diagnosis of PD. Likewise, a time discrepancy greater then one second was not evident in the group of healthy adults; such a discrepancy may be indicative of PD. These possibilities could be explored in a further investigation with a large number of recently diagnosed participants.

The null-hypothesis tested was that there is no difference between the way people turn in both directions. Whilst the significance tests gave no reason to reject the null hypothesis, closer inspection of the data, particularly delineating the 95% Limits of Agreement, suggests that individuals with PD rarely turn the same way in each direction.

8.3.4 Conclusion

Whilst the mean differences in performance turning in both directions were small, the limits of agreement were considerable in the PD Group because the standard deviations around the means were large and positive and negative changes were equally likely. People with PD showed more directional asymmetry than did the healthy adults, suggesting that a left-right discrepancy of two steps and/or one second might be indicative of PD. This possibility should be explored in a larger study.

8.4 Predicting Dysfunction during a DS Turn

For *some* people with PD turning might become dysfunctional when they are compelled to turn in the direction that they find most challenging. That is, some individuals turn effectively in one direction but when attempting to turn the other way their movements become discontinuous and/or they become unstable or dependent on assistance (they may even freeze and/or fall). The purpose of this analysis was to identify a component of the DU Turn that would *predict* dysfunction during the DS Turn, in people with PD. Benefits of being able to predict dysfunction from the DU Turn include:

a) Being alerted to an individual at risk of falling when performing the DS Turn.
b) Identifying an individual at risk of falling when turning in a particular direction without placing that individual at risk by having them attempt the DS Turn.
c) Reducing the time required to perform and analyse the SS-180 (if the DS part was predictable from the DU part).

The aim of the analysis was to propose a factor that could be tested (using a regression analysis) in a larger study with a different sample of people with PD.

8.4.1 Methods

For this exploratory analysis, the 29 participants with PD who had taken part in the studies outlined in Chapters Six and Seven were dichotomised into those who demonstrated dysfunction when performing a DS Turn and those who did not. Dysfunction during a DS Turn was defined as scoring zero on *any or all* of the following items in the Turn Quality Section: Continuity of Movement, Stability and Dependence during Turning. The four components of the DU Turn (Steps, Time, Type and Quality Score) were then considered as potential predictors of dysfunction when the direction of turn was imposed. The data were inspected visually and a cut-off point between the participants with and without a dysfunctional DS Turn identified. The sensitivity, specificity and predictive values of the chosen cut-off value were then calculated.

8.4.2 Results

Each row in **Table 8.8** summarizes the performance of a DU Turn by one participant; the first column indicates whether or not their DS Turn was defined as dysfunctional. The rows have been ordered according to the number of Turning Steps demonstrated during the DU Turn; those below the line took five or more.

Table 8.8. DS Turn Dysfunction and Predictors from the DU Turn

DS Turn Dysfunction	DU Steps	DU Time (sec)	DU Type	DU Quality
Yes	2	2	Pivotal	5
No	3	2	Lateral	5
No	3	1	Lateral	5
No	3	1	Lateral	5
No	3	2	Pivotal	5
No	3	2	Lateral	4
No	3	2	Lateral	4
No	3	2	Lateral	5
No	3	3	Lateral	5
No	4	2	Lateral	5
No	4	2	Incremental	5
Yes	4	2	Incremental	3
No	4	3	Incremental	3
No	4	3	Incremental	3
Yes	4	3	Incremental	5
No	5	2	Incremental	3
Yes	5	2	Incremental	4
Yes	5	3	Incremental	4
Yes	5	4	Incremental	4
Yes	5	5	Incremental	4
No	6	4	Incremental	5
Yes	6	5	Incremental	5
Yes	6	6	Incremental	4
No	7	4	Incremental	3
Yes	9	7	Incremental	0
Yes	10	8	Incremental	4
Yes	13	7	Incremental	4
Yes	14	7	Delayed	3
Yes	14	9	Incremental	2

For the sample studied, it was possible to predict dysfunction during the DS Turn from the use of five or more Turning Steps during the DU Turn, with 79% sensitivity and 80% specificity. As shown in **Table 8.9**, **14** people demonstrated dysfunction during the DS Turn. The proportion correctly predicted from the DU Turn was **11 / 14** or 79%.

One would predict that 79% of people with difficulty turning in a particular direction would take at least five steps when turning in their preferred direction.

Table 8.9. DS Turn Dysfunction: Actual and Predicted

	Actual DS Turn Dysfunction	**Actual DS Turn Without Difficulty**	**TOTAL**
Predicted DS Turn Dysfunction	**11**	3	14
Predicted DS Turn Without Difficulty	3	**12**	15
TOTAL	**14**	**15**	29

The other **15** participants did not demonstrate a dysfunctional DS Turn. The proportion correctly predicted from the DU Turn was **12 / 15** or 80%. That is, one would predict that 80% of those who turn in a specified direction without difficulty would take fewer than five steps when turning in their freely chosen direction. When *only* the performance of a standing-start turn in a freely chosen direction is observed, one can predict the proportion of people taking at least five steps who will demonstrate dysfunction when required to turn the other way. The positive predictive value of 5+ Turning Steps is 79%, i.e. 11 of the 14 who took five turning steps one way went on to demonstrate dysfunction when direction was specified. The negative predictive value of 5+ Turning Steps is 80%, i.e. 12 of the 15 who took fewer than five turning steps one way went on to turn in the other direction without difficulty.

8.4.3 Discussion

Having reviewed the available data on 29 people with PD, the best predictor of DS Turn Dysfunction was taking five or more Turning Steps during the DU Turn. Other components considered were not such good predictors (e.g. a 3s Turn Time, an Incremental Turn) and would take longer to measure than the Step Count. The suggested predictor requires further testing with a different and much larger sample. Two researchers would be required to minimise bias; one counting the steps taken during the DU Turn and one identifying dysfunction during the DS Turn.

8.5 Chapter Summary and Conclusion

This chapter addressed some of the factors that exacerbate the difficulty of turning. The interviews supported the notion that difficulty turning was exacerbated by both cognitive and physical factors (e.g. rushing and space limitation); cognitive or physical strategies may overcome the difficulty. Individuals with PD turned left and right differently: as the directional differences were greater than those observed in healthy adults, such differences (in Steps or Time) might support a diagnosis of PD. People who took five or more steps turning in the preferred direction (if that is what the DU Turn represents) were likely to demonstrate a dysfunctional DS Turn. This finding suggests a possible avenue for abbreviating the SS-180, making it more suitable for a clinical application.

Chapter Nine

Discussion

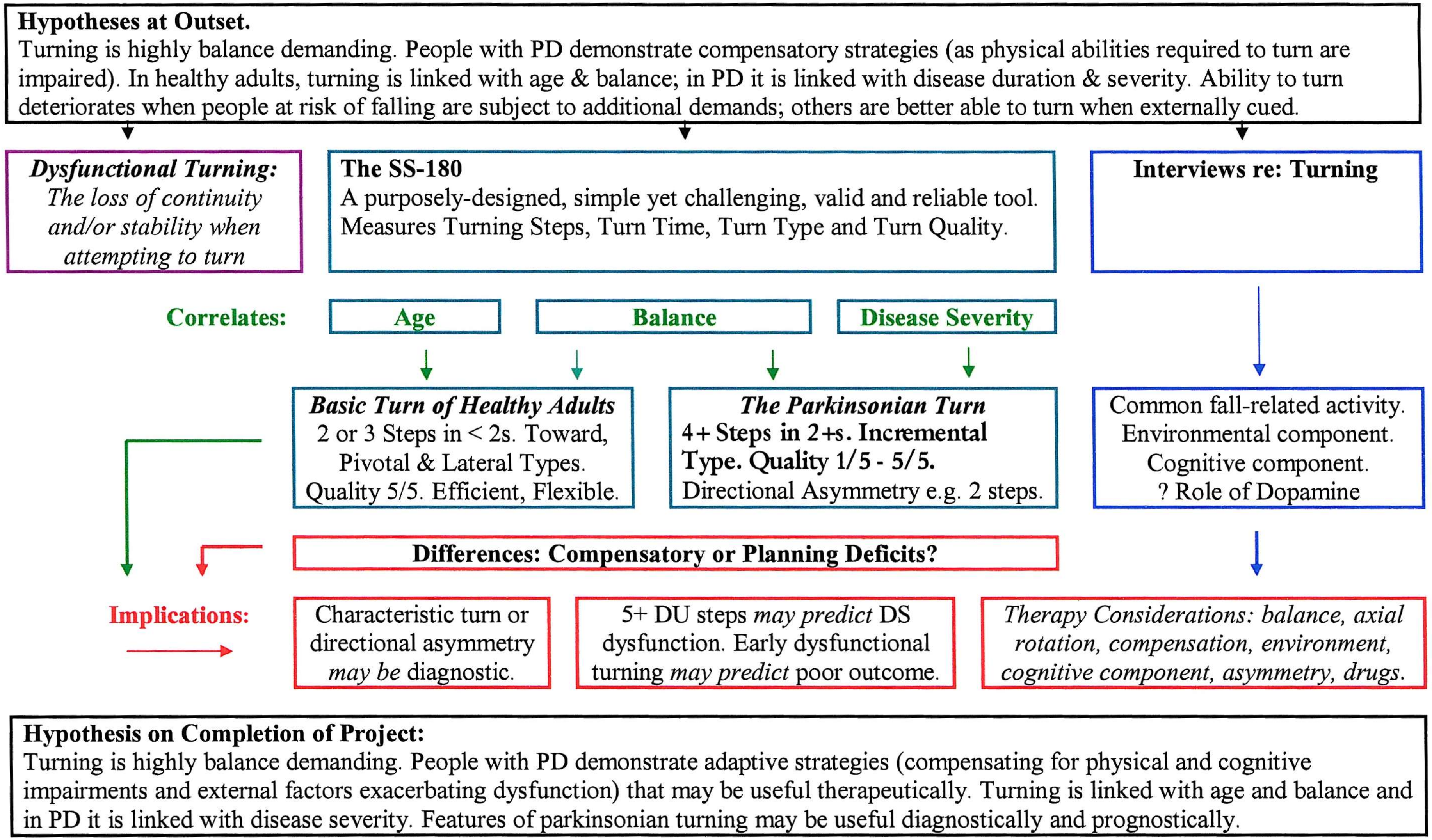
9.1. Introduction

In this chapter, the contributions made by this work to understanding dysfunctional turning are discussed, culminating in the proposal of further hypotheses. **Figure 9.1** summarises the pathway from the start point to the end point of this thesis, highlighting the contributions made at each stage; the chapter follows the same format. It begins with a discussion of the hypotheses set out at the beginning of the project (Section 9.2). Each of the three main strands of the work (defining dysfunctional turning, developing and using the SS-180 and interviewing people with PD about turning) is discussed separately (Sections 9.3 to 9.5). The decision to develop a *video-based* tool with which to describe turning was justified because, once again, the reluctance of people with PD to travel for a laboratory-based study was evident. The diagnostic, prognostic and therapeutic implications of the findings are pulled together in Section 9.6. Finally, in Section 9.7, conclusions are drawn and hypotheses for testing in further studies are set out.

9.2. Hypotheses Stated at the Outset

To turn safely, people with impaired balance adapt the way that they turn, because turning is a highly balance demanding activity. This was the reasoning behind the primary hypothesis stated in Chapter Two. People with PD are known to have impaired balance (postural instability is a cardinal sign) and known to associate turning with freezing and falling; why this might be (and how people manage their difficulties) is unclear from the literature. I reasoned that people with PD turned differently from healthy adults because a standing-start turn requires simultaneous and sequential movements, movements known to challenge people with PD. It seemed likely that the way healthy adults turned changed as they aged, while the difficulty people with PD experienced when turning increased as the disease progressed or could be exacerbated by external factors.

Figure 9.1. Summary of Contribution made by this work to Understanding Dysfunctional Turning in PD



I attempted to support or refute these ideas by:

1. Confirming that people with and without PD demonstrate different levels of balance control.
2. Identifying differences in the way that people with and without PD turned. These differences might be compensatory or increase the risk of falling when turning
3. Demonstrating links between turning and the turner's balance control and age.
4. Demonstrating links between turning and the turner's disease duration and severity.
5. Identifying the factors that exacerbate difficulty turning and the strategies that people with PD use to reduce their risk of freezing and/or falling when turning.

9.3. A Definition of Dysfunctional Turning

The first contribution made by this work is that:

The definition of Dysfunctional Turning as 'a loss of continuity and/or stability when attempting to turn' facilitates its description both in clinical practice and in further studies.

The definition emphasises that even people who are otherwise able to move freely and steadily find turning problematic. This is supported by the finding that although all the participants interviewed during this thesis were independently mobile, three-quarters reported difficulty turning. After reviewing the literature and talking to people with PD, continuity and stability appear to be the key elements of turning dysfunction, for example:

- Successful turning has been described as so smooth that walking continues with little change in timing (Hase and Stein, 1999)
- Freezing during turning has been described as a transient loss of leg movement (Giladi et al, 1992)
- Turning is one of the most common causes of falls among people with PD, though not among other populations.

Continuity and stability became items on the Turn Quality Section of the SS-180, linking the tool to the activity it was designed to evaluate. The interviews conducted confirmed that freezing and falling occur not only when turning but also when preparing to do so.

9.4. The Standing Start 180° Turn Test

The second contribution made by this work is that:

A way has been devised of characterising the basic turn demonstrated by a healthy adult and the typical parkinsonian turn.

The SS-180 was intended to capitalise on the strengths and overcome the limitations of earlier attempts to describe turning. For example, describing turning during a functional activity was difficult to standardise and the inter-rater agreement on Turn Type was unacceptable (Ashburn et al, 2001b) while describing walking 180° Turn Types proved reliable but failed to identify differences between people with and without PD (Ashburn and Stack, 1999). The SS-180 provides a way of standardising something often attempted informally in clinical settings. The continued use and further development of this test can be advocated, after having used it in the laboratory and the home. As long as sufficient space is available and the safety of the turner can be assured, the SS-180 should be workable in any setting. It provides a formal way of testing an individual's ability to turn in both directions and a succinct way of communicating the results, in terms of Turning Steps, Turn Time, Turn Type and Turn Quality. The design and development of the new test was prompted by the inadequate description of turning and the dominance of laboratory-based studies in the literature and was a central element of this thesis.

The SS-180 is a simple approach to evaluating a complex activity. A comprehensive evaluation of postural stability should 'challenge the balance control system' (Patla et al, 1992). The studies conducted here provided evidence that the SS-180 is challenging to both people with and without PD, one of the strengths of the new test.

Nieuwboer et al (1998) found little evidence of many reported motor symptoms when they tested people with PD under controlled conditions and similarly we were unable to discriminate between the turns demonstrated by people with and without PD during the Timed Up and Go Test. However, with the SS-180, people with PD were sufficiently challenged to demonstrate turns that were quite different to those demonstrated by healthy adults. The finding that one quarter of the participants tested at home needed assistance during the SS-180, more were unstable and even more failed to clear the floor with their feet lends validity to the test procedure. When some of the healthy adults tested attempted to turn from a standing start, they demonstrated Incremental Turns (characterised by several, small steps 'on-the-spot'). Such turns had not been demonstrated in our previous investigation and are not described elsewhere in the literature. The SS-180 might be among the most challenging of the available turn tests because it necessitates manoeuvring the COM through a potentially unstable phase while advancing toward a target not visible from the starting position.

Another of the strengths of the SS-180 is that it was developed with people with PD in mind. As such, dysfunctional turning is central, the instructions minimise cueing, one turn in each direction highlights directional asymmetry and the items have been chosen and worded for specific relevance to people with PD. During the laboratory-based study, some context-sensitivity (Yekutiel, 1993) was evident: after completing the test, one participant with PD said, "I don't think I'd have done it another day without falling". This observation supports the decision that was taken to conduct the main study in the home (in an attempt to overcome the temporarily enhanced performance that some people with PD experience when tested in a laboratory).

The video-based SS-180 has demonstrated external validity against a gold standard criterion measure and acceptable reliability. Its internal consistency and sensitivity to change still remain to be explored. The early results suggest that the SS-180 has the potential for abbreviation. Shortening the test would make it more applicable for routine clinical use. There are a number of ways in which the test could be abbreviated but further research would be necessary to demonstrate whether a shortened form of the test retained its validity and reliability.

It might be possible to eliminate one or more items from the tool; for example, Turning Steps was closely correlated with Turn Time and is implicit within the Turn Type definitions so could be superfluous. Another option would be to eliminate one section from the tool, for example, the Turn Quality Score. Finally, the analysis could be halved by eliminating the DU Turn; only the DS Turn (assumed to be more challenging) would require analysis.

The test has the potential to replace other measures of dynamic postural stability. This possibility should be explored in further research as such a quick measure would have a number of advantages over a longer, more complex test battery (such as the Berg Balance Test). Simpson et al (2002) made a similar claim for the TURN180, although that test only demonstrated an association with perceived unsteadiness on turning. The studies in this thesis demonstrate a link between the performance of the SS-180 and dynamic balance control (height-adjusted functional reach). This correlation and those between turning, age and PD severity are discussed below.

9.4.1 Correlates of the SS-180

The third contribution made by this work is the provision of evidence that:

The ability to turn from a standing start is linked with age and balance control and, in the case of people with PD, disease severity.

Among the healthy adults tested, age was positively correlated with Turning Steps and Turn Time and among the people with PD tested age was positively correlated with Turning Steps. These links are consistent with other research (Cao et al, 1997; Thigpen et al, 2000) and support the hypothesis stated earlier. Without an age-matched sample of controls in future studies, age-related features of turning could easily be wrongly attributed to pathology. To distinguish more clearly pathological changes from those that accompany normal ageing, it would be necessary to study more healthy adults of the age band in which PD is commonly diagnosed.

From this investigation it appears that with increasing age people are more likely to turn 'on-the-spot' prior to walking towards their goal (one feature of the characteristic parkinsonian turn) but longitudinal studies would be necessary to chart changes in an individual's standing-start turns over time.

Every study conducted during this project revealed a close correlation between balance control (height-adjusted FR) and turning. Among the healthy adults and the people with PD tested, balance control was negatively correlated with Turning Steps and Turn Time. This is consistent with other studies (Tinetti et al, 1986; Lipsitz et al, 1991; Shenkman et al, 1996; Cao et al, 1997; Thigpen et al, 2000; Simpson et al, 2002) and supports the hypothesis stated earlier. Height-adjusted FR showed a very close linear relationship with FR and is recommended for the measurement of balance in further studies as it provides a meaningful indicator of FR in participants of different heights. The work undertaken supported the hypothesis that people with and without PD differ in their dynamic balance control: the 29 people with PD tested had a median height-adjusted FR equal to 11% of the height and the 43 healthy adults tested had a median height-adjusted FR equal to 20%.

In the literature, turning has been linked with both disease duration and severity (e.g. Charlett et al, 1998; Steiger et al, 1996; Kamsma et al, 1994). The studies described in Chapters Five and Seven demonstrated a link between the SS-180 and disease severity (both in terms of symptom severity rated on the UPDRS and self-assessed disability rated on the SAS). People with more severe PD took more Turning Steps and longer Turn Times than did people with milder disease, suggesting that their need to modify their turning strategy was greater. Longitudinal studies would be needed to chart the progression of dysfunctional turning and the adaptation of the basic standing start turn. The expectation that the people with PD who participated in the studies would be at the milder end of the spectrum proved unfounded. A strength of the approach taken here was that people with severe PD (Grade IV) took part in both the laboratory-based and the home-based investigations; other studies have been limited by the exclusion of such individuals.

9.4.2 The Standing Start Turns of People with and without PD

The main contribution made by this work is:

The description of turning in people with and without PD and the identification of differences between the two groups' performances.

Healthy adults were recruited not to define 'normality' but to serve as a background against which the adaptive features of parkinsonian turning could be highlighted. The basic turn demonstrated by a healthy adult can be characterised in the following way:

- Two or three Turning Steps and complete in under two seconds
- Lateral, Toward and Pivotal Turn Type (usually the same in each direction)
- Maximal Turn Quality Score, i.e.
- Initiated with a different foot in each direction (usually the inside foot)

Healthy adults turned efficiently, combining the rotational component of the SS-180 with advancing toward the target. The basic turn was demonstrated consistently by the healthy adults studied. Evidence to support this statement comes from the little change measured when people repeated the SS-180 in the laboratory and when turns in each direction were compared.

The characteristic turn demonstrated by people with PD can be characterised in the following way:

- Four or more Turning Steps and complete in two or more seconds
- Incremental Turn Type
- Sub-maximal Turn Quality Score

People with PD turned inefficiently, completing the rotational component of the SS-180 'on-the-spot' before advancing toward the target. Unlike the healthy adults studied, the sample of people with PD demonstrated directional asymmetry.

Evidence to support this statement comes from the finding that when turns in each direction were compared a difference of two Turning Steps and/or more than one second was not uncommon. These initial descriptions will be refined as the new protocol is used in other studies. The key differences identified so far between the standing start turns of people with and without PD were related to the Turning Steps and Turn Time, the Movement-initiating Foot, the combination of rotation and translation (reflected by Turn Type), Turn Quality and Directional Asymmetry. These differences may reflect:

a) Compensation (by which the individual with PD adapts the basic highly balance demanding turn in light of his or her postural instability), or
b) A planning deficit (in which case the individual with PD is unable to access and organise the motor programme for turning that is deployed by a healthy adult).

It would be useful therapeutically to be able to distinguish compensatory adaptations from the features of dysfunctional turning that stem from a planning deficit as the former could be encouraged and it may be possible to ameliorate the latter.

A standing start turn might be more challenging than straight forward gait because:

a) The target cannot be visualised from the outset and the visual input *whils*t orientating the gaze toward the target is a moving stimulus.
b) The timing is more complex and the basal ganglia are thought to play a part in organising the temporal parameters of movement. Both legs perform different movements when turning which must be co-ordinated.
c) One foot crosses and clears the other (increasing the need for dorsiflexion); in straight forward gait the trajectory of each foot does not hinder the trajectory of the other.
d) The contact made between the foot and the floor differs from the (highly stable and efficient) heel strike of straight forward gait. Nieuwboer et al (1999) demonstrated that a flat-footed gait might increase the risk of tripping.
e) Turning is highly balance-demanding, involving a phase of dynamic instability before the base is brought under the moving COM.

As such, it is likely that people with PD would modify the way in they turn. Thigpen et al (2000) argued that Turn Type was selected in response to 'subtle changes in balance' and it seems likely that several of the features of the parkinsonian turn described here also evolve as balance control deteriorates. Steiger et al (1996) suggested that people with PD adopted 'inappropriate turning strategies' but one can argue that people with PD adapt the way that they turn in what are entirely *appropriate* ways. The multiple stepping parkinsonian turn, for example, might be an adaptation of the basic turn deployed by healthy adults (most of who demonstrated just two or three Turning Steps in this study). Increasing the number of steps taken while turning reduces the size of each step and the length of time spent in 'single stance'. It would be an appropriate compensation for reduced range of movement (from weakness, rigidity or secondary limitations and postural instability. Unfortunately, when every Turning Step is an opportunity to freeze or trip, this adaptation to the basic turn might itself increase the risk of dysfunction.

The slow parkinsonian turn may be another adaptation of the basic turn if it facilitates the co-ordination of the two lower limbs. Turning more slowly than usual compensates for the inability to move the feet quickly enough to bring the base of support into an appropriate position. As planning seems to be an important component of a safe and successful turn (as was evident from the interviews), turning slowly provides more time to plan the manoeuvre.

Similarly, breaking the standing start turn down into its rotational and straight forward components allows each stage to be planned and executed in isolation, simplifying the task. This reduces the efficiency of the turn but, as Morris et al (2001) argued, people with PD sacrifice efficiency for stability. Two items on the Turn Quality Section of the SS-180 might also reflect appropriate adaptations of the basic turn, i.e. using external support or lowering one's centre of gravity to enhance stability while turning. Alternatively, the features of parkinsonian turning may not be compensatory but instead reflect the inability of people with PD to execute a motor programme for turning as healthy adults do.

Differences in the turns observed could not be attributed to differences in the starting positions adopted by the groups with and without PD but, when moving from those starting positions, there were differences that may have reflected planning deficits. A greater proportion of the healthy adults began to turn by moving the foot ipsilateral to the direction in which they were turning. Repositioning the inside foot first may be stability enhancing or it may facilitate axial rotation but it may represent failure to initiate turning as healthy adults do. Likewise, in the laboratory-based study (Chapter Six) examples of Delayed Onset Turn Types were observed; people with PD demonstrated a number of attempts to turn without actually moving from the starting position. Another feature of parkinsonian turning that may reflect a planning deficit was the smaller magnitude of the Turning Steps in comparison with the healthy adults. The dopaminergic pathways have been shown to influence force-production during self-generated step initiation (Burleigh-Jacobs et al, 1997). It may be that, rather than enhancing stability, multiple small Turning Steps reflect the inability to take a step of the appropriate size. Finally, the inability to rotate towards the target *while* advancing toward it may not be an adaptation that simplifies a standing start turn but, instead, a reflection of the inability to run the two programmes (for turning and walking) together. Further research would be necessary to distinguish the active adaptations of turning from those that are consequences of planning deficits.

In parallel with testing the ability of people to turn, the participants with PD were interviewed about the difficulties that they had experienced when turning. This strand of the work is discussed in the following section, before the implications of the findings as a whole are considered.

9.5. Difficulties Associated with Turning

Other contributions made by this work are:

The finding that dysfunctional turning is reported even by people who have been only recently diagnosed and the confirmation that turning is a common fall-related activity in PD.

Among people with PD, turning is renowned for provoking freezing and falling. Three-quarters of the repeat-fallers interviewed had fallen turning; repeat-fallers are known to be at high risk of hip fracture as are people who fall turning. The physical environment contributed to many of the turn-related falls described. The occasions when it is necessary to turn in a confined space are numerous; identifying how an individual with PD attempts to do so remains to be established but would be worth exploring in a future study. The interviews confirmed that, for many people, freezing and/or falling occur when preparing to turn or even thinking about doing so, i.e. before postural instability is threatened by a balance-demanding manoeuvre. Therefore, further research on dysfunctional turning would need to address not only the action of turning but also the cognitive factors underpinning the perceived need to turn and the preparation to do so. Some individuals reported that their ability to turn fluctuated with the timing of their antiparkinsonian medication, yet disordered axial rotation is thought to arise from lesions in non-dopaminergic pathways. It may be that when the available dopamine levels change, a mismatch arises between axial and distal function; axial function remains constant but the ability to move the lower limbs fluctuates. People may be most at risk of falling when they can take fast or large turning steps but still do not have the axial stability to do so safely.

9.6. Implications of the Findings

9.6.1. Diagnostic Implications

Rao et al (2003) recently reviewed the literature on the clinical diagnosis of PD and concluded that features such as 'shuffling gait', difficulty turning in bed and difficulty rising from a chair should be carefully reviewed in all patients with suspected PD, along side the cardinal signs. Despite the widely acknowledged belief that turning difficulties are characteristic of PD, the possibility that *this* sign could have any diagnostic or a prognostic value has not been explored. The SS-180 may have a value in the diagnosis of PD, a condition that is difficult to diagnose accurately in the early stages. Postural instability tends to be considered one of the later symptoms to present in PD but, as the results of the main study showed (Section 7.3), dysfunctional turning may be experienced within a year or two of diagnosis. There may be individuals who notice increasing difficulty turning but would not think to mention it to a health care professional because they attach to it no significance. Difficulty turning may be, however, a useful symptom for which to probe.

Using the *characteristic parkinsonian turn* identified here might be useful in supporting or refuting a diagnosis as, on every section of the SS-180, the participants with and without PD differed significantly. *Directional asymmetry* too might be a feature that distinguishes between people with and without PD and should be investigated further. People without PD tended to turn similarly in both directions but individuals with PD rarely turned the same way to their left and their right; for example, a quarter of those with PD demonstrated a difference of two or more Turning Steps. Even if further research showed the prevalence of a) the *characteristic turn* or b) *directional asymmetry* to differ between groups of people with and without PD, neither feature could be considered a diagnostic test. A diagnostic test allows patients to be classified into a group according to the test result (Altman, 1991). At best, after extensive research, they could be considered 'clinical features useful in the diagnosis of PD' (Rao et al, 2003).

No data were collected during the production of this thesis with the intention of promoting the SS-180 as a diagnostic tool. At this stage, one can only reflect on the results of the first investigations in which the standing-start turns of people with and without PD have been systematically evaluated and suggest that difficulty turning from a standing-start might eventually be added to the list of motor difficulties that are commonly accepted as symptomatic of parkinsonism (e.g. turning over in bed, handwriting, undoing buttons). In order to explore the possibility that the SS-180 could contribute usefully to the diagnosis of PD, further research would be necessary in the following domains:

- Clinicians need to know what proportion of patients with 'abnormal' test results are truly 'abnormal' (Altman, 1991). The positive and negative predictive values of a test reveal the proportion of patients with positive and negative test results respectively who are correctly diagnosed. To explore the positive and negative predictive value of the SS-180 (i.e. in the case of PD, predicting the diagnosis rather than the patients 'true condition') it would be necessary to test a considerable number of people thought to be in the early stages of PD and a similar number of elderly controls and follow them over time (with the researcher analysing the SS-180 blind to the diagnosis).

- It would be necessary to establish how the SS-180 is performed by people with those conditions that commonly mimic PD (such as progressive supranuclear palsy, multiple system atrophy and corticobasal degeneration) before suggesting that the test has a contribution to make to the diagnostic process.

In summary, when reflecting on the potential uses of the SS-180, one can argue that dysfunctional turning (as indicated with the new turn test) might have a place alongside other 'clinical features useful in the diagnosis of PD'. Further research would be required to explore this possibility. Many clinicians make informal assessments of their patients' motor difficulties that are commonly accepted as symptomatic of parkinsonism; the advantage of the SS-180 is that it is a simple and reliable test that allows one clinical feature to be evaluated systematically in the clinic.

9.6.2. Prognostic Implications

Thigpen et al (2000) concluded that 'a functional assessment that accurately measures difficulty turning would be a useful clinical tool for the early recognition of those individuals at risk of falling'. This work has shown that people with PD who take five or more Turning Steps when turning in their preferred direction are at considerable risk of dysfunction when turning in the opposite direction. Further research is required to establish the predictive value of five or more Turning Steps but the immediate implication is that people demonstrating this feature are at risk of falling. Individuals who demonstrate particular difficulty turning in one direction might benefit from physiotherapy or reorganising the environment in which live.

Some individuals with PD (for example, those who do not report difficulty turning) may be appropriately adapting the way they turn in parallel with their motor deterioration, while others (those who do report difficulty) fail to adapt. This might explain the finding that disease duration and the ability to turn were not closely correlated: dysfunctional turning would not appear to worsen over time, as long as the adaptation of turning kept pace with disease progression. The inability to adapt appropriately early in the disease course (reflected by dysfunctional turning at the time of diagnosis) might indicate a poor prognosis or failure to benefit from particular therapies; further study is indicated.

9.6.3. Therapeutic Implications

Whether or not people with PD adapt the way that they turn, they remain at risk of falling because, for example:

- Turning requires the co-ordination of different motor programmes for each lower limb
- Multiple stepping equates with multiple opportunities to freeze or trip and
- The loss of axial rotation makes securing a stable frame of reference difficult.

Plant et al (1999) defined the purpose of physiotherapy in PD as maximising functional ability and minimizing secondary complications 'through movement rehabilitation within a context of education and support for the whole person'. In keeping with this framework, gait re-training and specific fall-prevention measures for people with PD who report difficulty turning might prove very beneficial. Having completed the interviews and movement analyses detailed in this thesis, one would strongly advocate that physiotherapists make an effort to identify the specific circumstances in which their patients experience movement difficulties, particularly falls. People with PD are believed to benefit from physiotherapy (de Goede et al, 2001) but to date there is little research to demonstrate whether physiotherapy does decrease the difficulty of turning. The findings of this thesis suggest that the following six targets might have therapeutic potential; in each case further research to demonstrate efficacy is indicated.

- As it is probably postural instability that triggers the need for adopting compensatory turning strategies and as a link between balance and turning has been demonstrated, **balance retraining** would be a rational target for people who are at risk of falling when turning. Spinal flexibility has been shown to contribute to dynamic balance control and is often restricted in people with PD (Schenkman et al, 2000), so measures aimed at increasing spinal flexibility should be incorporated into a therapeutic programme.

- **Improving axial rotation** might facilitate head movement during turning, allowing people at risk of falling to achieve an earlier visual fix on a frame of reference as they turn. Physiotherapeutic techniques for strengthening the trunk muscles and increasing spinal rotation in people with PD have been described by authors including Bridgewater and Sharpe (1997) and Schenkman et al (1998).

- Therapists could **promote the useful adaptations** identified here for patients having difficulty turning (e.g. slowing down, breaking down turning into component parts) and work towards eliminating the features of turning that increase the risk of falling (e.g. poor ground clearance). Kamsma et al (1995) demonstrated that people with PD benefited from a movement strategy retraining programme in that they were able to use the strategies in their everyday lives.

- **Modifying the domestic environment** so that turns in tight spaces are minimised might reduce the frequency of fall-events that have an environmental component. For example, tasks such as making a cup of tea could be made safer for patients at risk of falling if they rearrange the necessary items into one place in the kitchen so that repeated turns are not required when both hands are full. Furthermore, moving a bed against a wall eliminates one of the pathways beside the bed from which a turn is required. Clearing a cluttered living space allows more straight forward movement throughout the home and reduces the need to change direction.

- For those individuals who experience dysfunction prior to beginning to turn, the value of a **cognitive strategy** for negotiating the manoeuvre could be explored. Yekutiel et al (1991) described 'freeing the concept of the task from conceptual restrictions derived from the physical environment', using the example of walking round the corner of a bed. The authors advocated teaching the patient to see a continuous curve rather than two paths at right-angles. Nieuwboer et al (1997) reported a case study in which the subject experienced a reduction in freezing episodes while negotiating obstacles after learning to use external cues.

- A therapist could encourage an individual with difficulty turning to find out whether turning was safer in a particular direction, or **use directional asymmetry** to indicate a unilateral weakness or loss of range that might be amenable to intervention, thus improving the ability to turn.

9.7. Concluding Remarks

In this work, people with PD demonstrated more impaired dynamic balance control (a significantly shorter height-adjusted functional reach) than did healthy adults. Turning is a highly balance demanding activity and was commonly associated with fall-events among the sample. Turning from a standing start is highly balance demanding and the ability to do so was linked with the level of dynamic balance control. People with and without PD turned differently from a standing start and the differences may reflect the need of people with PD to adapt the basic turn in light of their physical and cognitive impairments. The adaptive features of a parkinsonian turn might be useful therapeutically. In comparison with healthy adults, people with PD took more steps during the SS-180, turned more slowly, demonstrated different turn types and made less progress toward the target. The characteristic parkinsonian turn might have diagnostic or prognostic applications.

People with PD reported that turning was even more difficult when they were in a confined space or having to move quickly without time to plan the manoeuvre; they were more likely than were healthy adults to turn differently in each direction. Age was linked with the way a healthy adult turns but disease severity was the more important correlate in PD.

The following hypotheses are proposed for investigation in further studies:

- The characteristic parkinsonian turn and/or directional asymmetry at the time of diagnosis is supportive of a diagnosis of PD.
- Five or more Turning Steps during a DU Turn is predictive of dysfunctional turning when direction is imposed.
- People with Dysfunctional Turning improve their ability to turn after a course of physiotherapy emphasising balance retraining and improving axial rotation.
- Repeat fallers with PD who have fallen turning will fall less frequently after a course of physiotherapy emphasising as appropriate balance retraining, improving axial rotation, adopting compensatory strategies, modifying the environment and developing a cognitive strategy.

10- Appendices

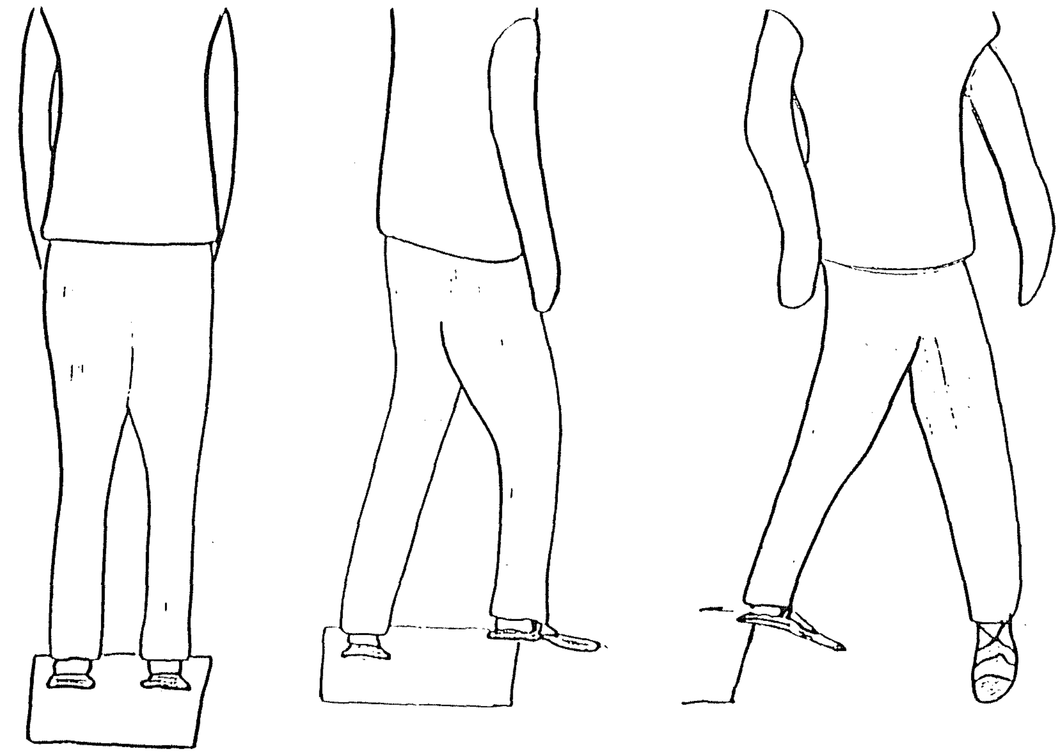
APPENDIX 1

Visual Representations of Turn Types

A <u>Pivotal</u> Type Turn to the Right

A **Pivotal** Turn is completed in two or three turning-steps. The initial step (with the inside foot) is wider than it is long, followed by a second wide step (with the outside foot).

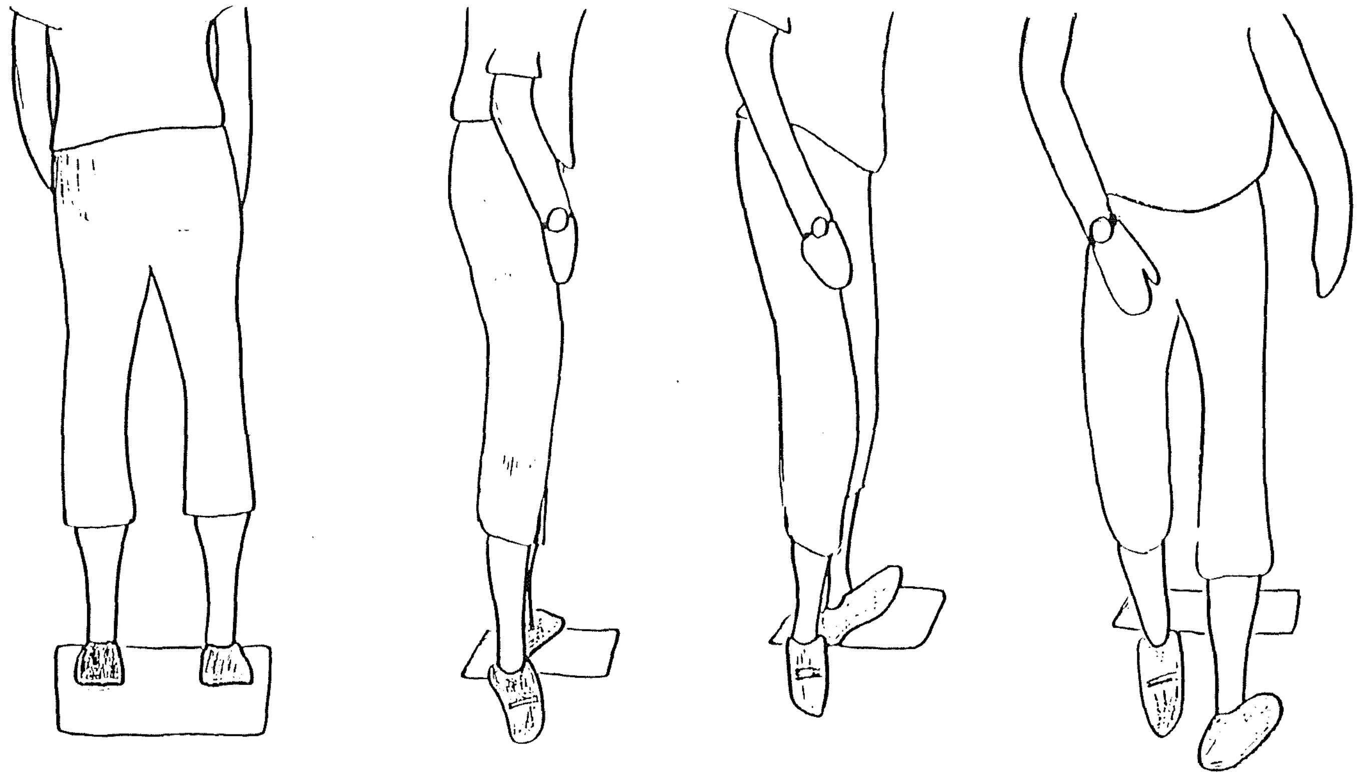
In the laboratory, healthy adults took an initial turning step the width of which was a median 11% of their height, followed by a second step the width of which was a median 33% of their height.



A **Toward** Type Turn to the Right

A **Toward** Turn is completed in two turning-steps. The first foot moved is always the same side as the direction of turn. There is direct advance toward the target, with negligible lateral deviation.

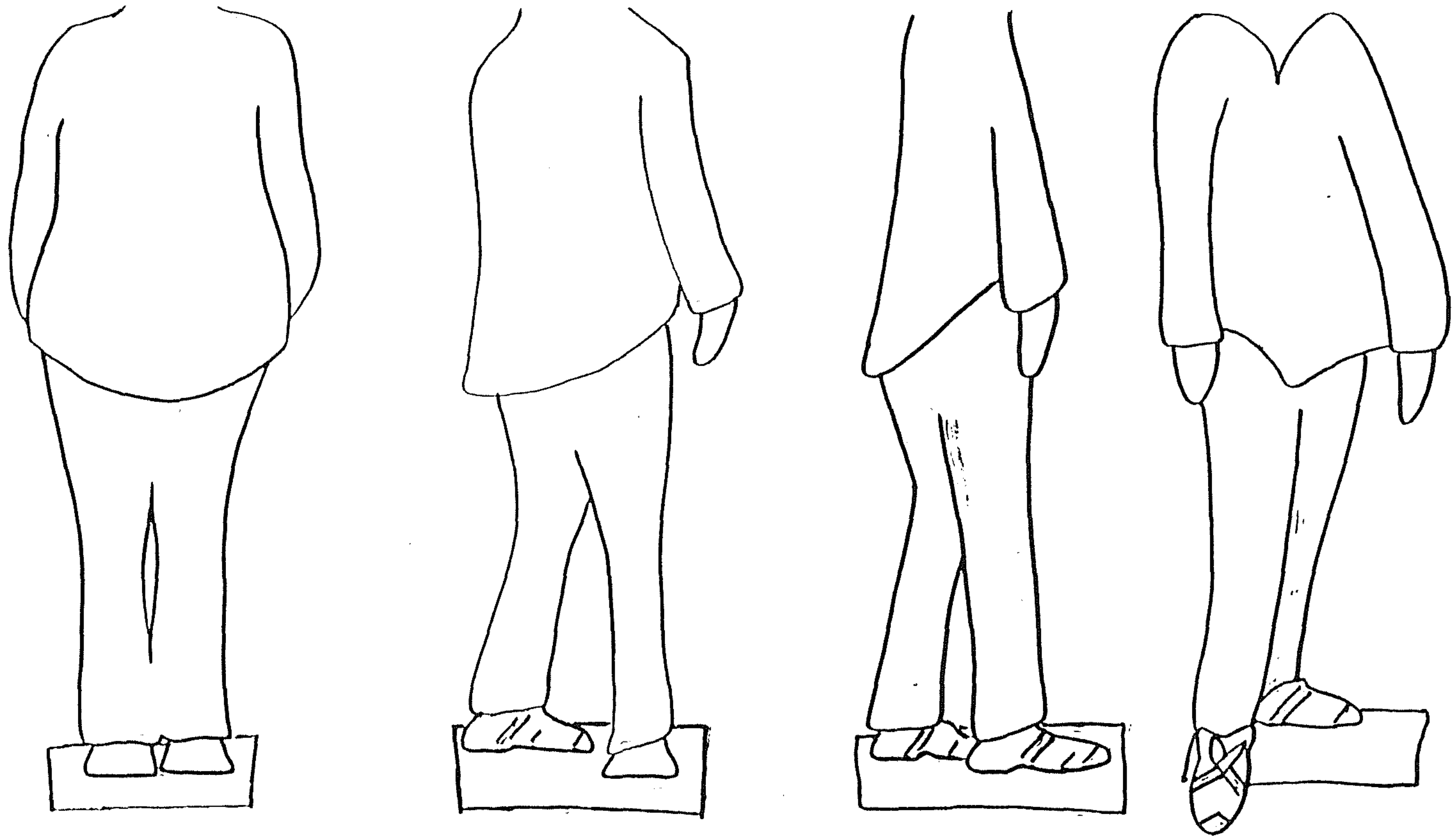
In the laboratory, healthy adults took an initial turning step that moved them a median 21% of their height toward the target, followed by a second step that moved them nearer the target by a median 64% of their height.



A <u>Lateral</u> Type Turn to the Right

A **Lateral** Turn is complete in two or three turning-steps. The first foot moved is always the opposite side to the direction of turn.

In the laboratory, healthy adults took an initial turning step the width of which was a median 5% of their height, followed by a second step that moved them nearer the target by a median 17% of their height.



APPENDIX 2

Local Research Ethics Committees Approval

Southampton
University
Hospitals
NHS Trust

Southampton & S.W. Hants
Joint Research Ethics Committee
Trust Management Offices
Mailpoint 18
Southampton General Hospital
Tremona Road
Southampton SO16 6YD

Tel 01703 794912
Fax 01703 798678

Ref: CPW

4 March 1999

Ms E Stack
University Rehabilitation Research Unit
Level E, Mailpoint 46
SGH

Dear Ms Stack

RE: 046/99 - Movements used when turning and the factors influencing the ways in which people with Parkinson's disease turn.

The Joint Ethics Committee considered your application for the above study at its recent meeting and I am pleased to inform you that **approval was given**.

May I draw your attention to the enclosed conditions of approval which **must be complied with. In particular: it is mandatory that ALL correspondence, information sheets, consent forms, adverts etc, carry the LREC submission number.**

This committee is compliant with the International Committee on Harmonisation/Good Clinical Practice (ICH) Guidelines for the Conduct of Trials involving the participation of human subjects as they relate to the responsibilities, composition, function, operations and records of an Independent Ethics Committee/Independent Review Board. To this end it undertakes to adhere as far as is consistent with its Constitution, to the relevant clauses of the ICH Harmonised Tripartite Guideline for Good Clinical Practice, adopted by the Commission of the European Union on 17 January 1997.

The composition of the committee is enclosed for your files and confirms which members were present at the meeting. Most pharmaceutical companies request this information and we would be grateful if you could forward this to them if appropriate.

Should any unforeseen problem of either an ethical or procedural nature arise during the course of this research and you feel the Joint Ethics Committee may be of assistance, please do not hesitate to contact us.

Yours sincerely,

CWilkinson

Clair Wilkinson (Ms)
Administrator

PRIVATE & CONFIDENTIAL

University of Southampton | Finance Department

Memorandum

From:	Ruth McFadyen	**To:**	Ms Emma Stack
Ext:	22417	**Dept:**	Rehabilitation Research Unit
E-mail:	hrm@soton.ac.uk	**Date:**	7 February 2001

Reference: CLNTRL/HRM/GFT

Professional Indemnity Insurance

Project No: **046/99**

Movements Used When turning and the Factors Influencing the Way in Which People with Parkinson's Disease Turn

Thank you for forwarding the completed questionnaire and attached papers.

Having taken note of the information provided, I can confirm that this project will be covered under the terms and conditions of the above policy, subject to written consent being obtained from the participating volunteers.

Ruth McFadyen

Ruth McFadyen
Insurance Administrator

APPENDIX 3

Participant Consent Forms

Health and Rehabilitation Research Unit

Professor Ann Ashburn
PhD MPhil MCSP
Head of Unit

School of Health Professions and Rehabilitation Sciences

Professor R E Barnitt
PhD MSc FCOT
Head of School

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Fax +44 (0)23 8079 4340
Email A.M.Ashburn@soton.ac.uk
WWW http://www.sohp.ac.uk/sohp

Consent Form for People <u>without</u> Parkinson's Disease (LREC No. 397/B)

Comparing People with and without Parkinson's Disease performing the Standing Start 180° Turn Test

I . . . . .agree to take part in this study. The study has been explained to me and I have had an opportunity to ask questions about it. I understand that I may leave the study *at any time*, without giving a reason for doing so and without prejudicing any healthcare that I may need in the future. I understand that if I take part in the study:

- A researcher (Ms E Stack) will visit me once at home, to collect data.
- I will be asked how I manage everyday activities, whether I have had any falls recently and whether I have any problems when I turn round.
- The researcher will test my balance when I am standing.
- I will be asked to walk towards a target behind me while a video camera records how I move.
- If I do not want to answer a particular question or attempt a particular test, I do not have to. The researcher will leave such sections out.
- Only the researchers involved in this study will use my video record. The others researchers involved are Professor A Ashburn and Dr H Rassoulian of the University of Southampton.
- Any information collected about me will be strictly confidential. The video data collected will be stored securely unless I ask for the tape to be destroyed at the end of the study.

Signed   Date

Signed (Researcher)   Date

CONSENT TO USE VIDEO WHEN PRESENTING STUDY FINDINGS

I understand that, if I agree, my video record may be shown to an audience of health care professionals and researchers to help explain the results of the study.

My video record may / may not *(delete as appropriate)* be shown to an audience of health care professionals and researchers when the findings of the study are being presented.

Signed   Date

CONSENT TO STORE OR DESTROY VIDEO DATA

Delete as appropriate

I agree that my video data may be stored securely by the Health and Rehabilitation Research Unit at The University of Southampton, in keeping with the policy on Research Governance

or

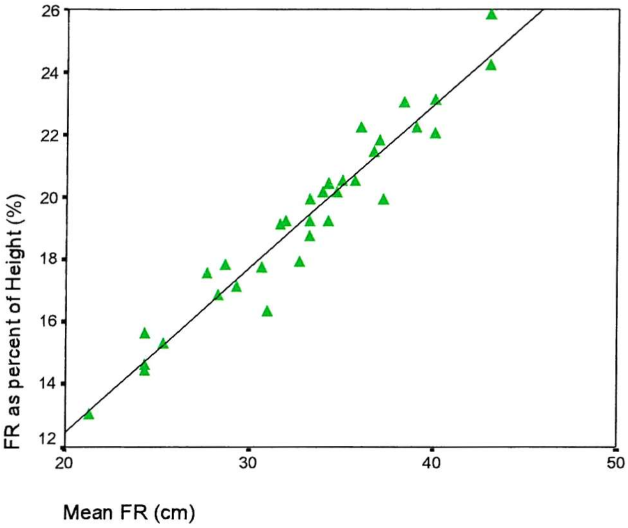
I would prefer that my video data be destroyed no later than six months after the end of the study, rather than stored.

Signed   Date

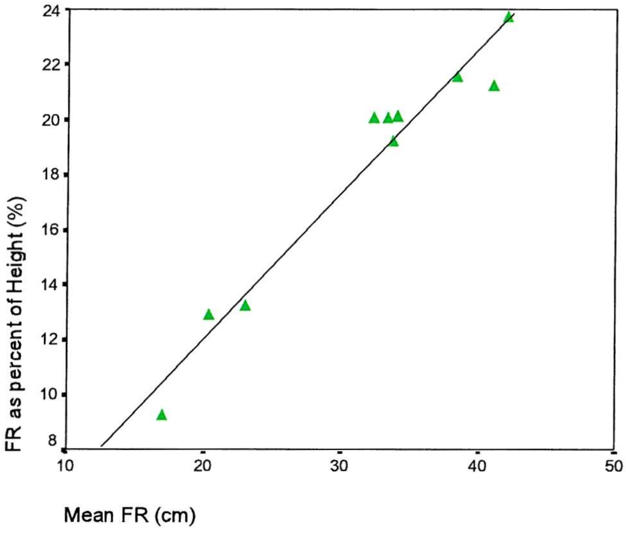
APPENDIX 4

The Relationship between FR and Height-adjusted FR

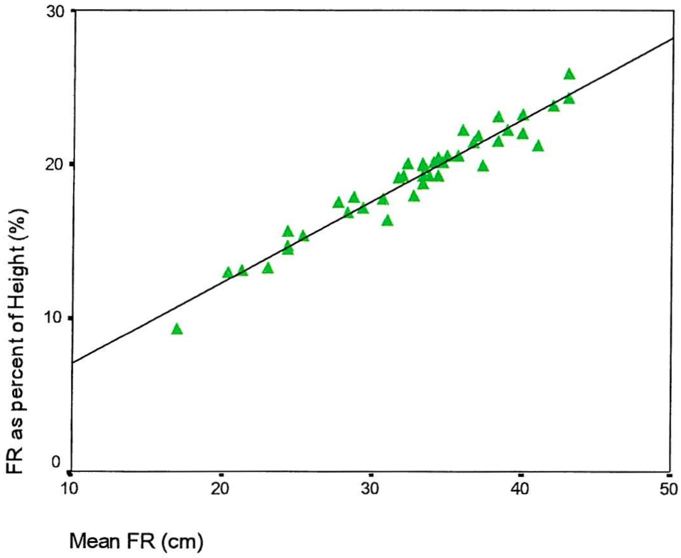
The 31 healthy adult participants in the laboratory-based study (Chapter Five).



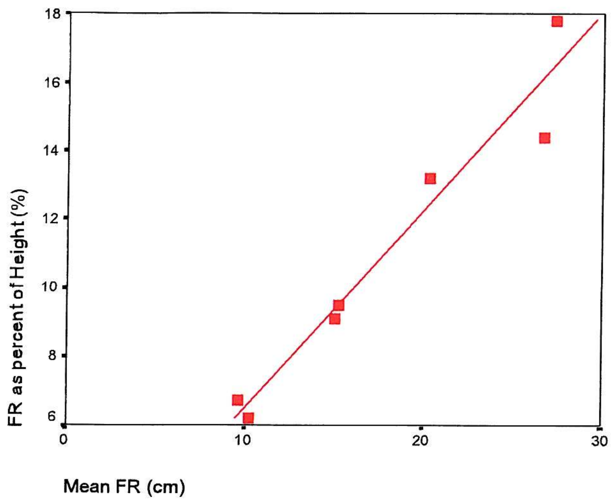
The ten healthy adult participants in the main study (Chapter Seven).



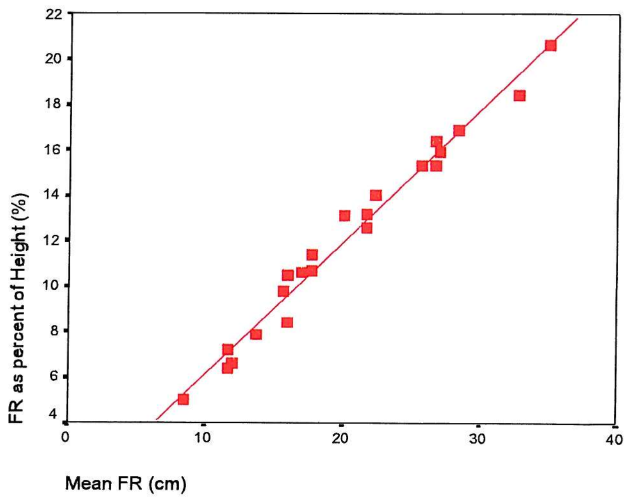
All 41 Healthy Adult Participants



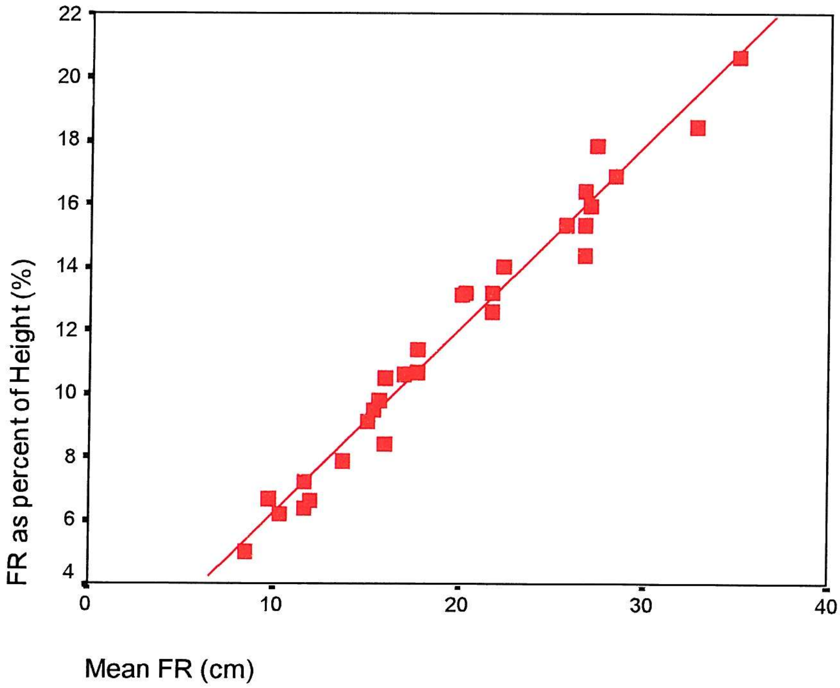
The seven participants with PD in the laboratory-based study (Chapter Six).



The 22 participants with PD in the main study (Chapter Seven).



All 29 participants with PD



APPENDIX 5

Correlation between Turning Steps and Turn Times

Turning Steps and Turn Times: Healthy Adult (laboratory) Study (n = 31)

		DU Time	DS Time	Mean Time	DU Steps	DS Steps
DS Time	r_s	.628				
	P	.000				
Mean Time	r_s	.881	.922			
	P	.000	.000			
DU Steps	r_s	.739	.618	.745		
	P	.000	.000	.000		
DS Steps	r_s	.348	.595	.536	.595	
	P	.055	.000	.002	.000	
Mean Steps	r_s	.619	.680	.722	.903	.882
	P	.000	.000	.000	.000	.000

Turning Steps and Turn Times: PD laboratory-based study (n = 7)

		DU Time	DS Time	Mean Time	DU Steps	DS Steps
DS Time	r_s	.857				
Mean Time	r_s	.929	.964			
DU Steps	r_s	1.000	.857	.929		
DS Steps	r_s	.852	.964	.927	.852	
Mean Steps	r_s	.964	.929	.964	.903	.927

Turning Steps and Turn Times: People with PD in the main study (n = 22)

		DU Time	DS Time	Mean Time	DU Steps	DS Steps
DS Time	r_s	0.774				
	P	0.000				
Mean Time	r_s	0.908	0.963			
	P	0.000	0.000			
DU Steps	r_s	0.918	0.593	0.769		
	P	0.000	0.004	0.000		
DS Steps	r_s	0.873	0.823	0.891	0.814	
	P	0.000	0.000	0.000	0.000	
Mean Steps	r_s	0.941	0.739	0.869	0.956	0.949
	P	0.000	0.000	0.000	0.000	0.000

Turning Steps and Turn Times: Healthy Adults in the main study (n = 10)

		DU Time	DS Time	Mean Time	DU Steps	DS Steps
DS Time	r_s	0.542				
Mean Time	r_s	0.852*	0.875*			
DU Steps	r_s	0.632*	0.548	0.586		
DS Steps	r_s	0.425	0.762*	0.633*	.748*	
Mean Steps	r_s	0.451	0.745*	0.630	.789*	.996*

* = Significant at the 5% Level

APPENDIX 6

Measures of Disease Severity

The Parkinson's Disease Self-assessed Disability Scale (Brown et al, 1988)

Participants were asked to indicate how much effort they found the accomplishment of the following 25 everyday activities at the times that they usually attempted them. Responses were on a five-point scale from one to five, giving a minimum possible score of 25 (i.e. every activity accomplished without difficulty) and a maximum possible score of 125 (i.e. unable to accomplish any of the activities).

1. Get out of bed
2. Get up from armchair
3. Walk up stairs
4. Walk down stairs
5. Get dressed

6. Get undressed
7. Get into bath
8. Get out of bath
9. Walk indoors
10. Walk outside

11. Wash & dry dishes
12. Pick up object off floor
13. Insert or remove plugs
14. Make tea or coffee
15. Hold cup & saucer

16. Pour milk
17. Wash face & hands
18. Brush teeth
19. Cut food with knife & fork
20. Hold & read a newspaper

21. Dial telephone
22. Use public transport
23. Open tins
24. Write a letter
25. Turn over in bed

1 =	Accomplished alone without difficulty
2 =	Accomplished alone with a little effort
3 =	Accomplished with a lot of effort or a little help
4 =	Only accomplished with a lot of help
5 =	Unable to do

Unified Parkinson's Disease Rating Scale

(Lang and Fahn, 1989)

1. Speech	0 1 2 3 4	Normal Slight loss Monotonous Marked impairment Unintelligible	**8. Pronation Supination**	0 1 2 3 4	Normal Mild reduction Moderately impaired Severely impaired Barely Able
2. Expression	0 1 2 3 4	Normal Min hypomimia Slight diminution Mod hypomimia Masked	**9. Leg Agility**	0 1 2 3 4	Normal Mild reduction Moderately impaired Severely impaired Barely Able
3. Resting Tremor	0 1 2 3 4	Absent Slight & infrequent Mild Moderate intermittent Persistent	**10. Rising**	0 1 2 3 4	Normal Slow or 2+ Pushes Tends to fall Needs help
4. Action Tremor	0 1 2 3 4	Absent Slight Moderate (action) Moderate (holding) Interferes ++	**11. Posture**	0 1 2 3 4	Normal Not erect Moderate stoop Severe stoop Marked flexion
5. Rigidity	0 1 2 3 4	Absent Slight Mild / moderate Marked Severe	**12. Gait**	0 1 2 3 4	Normal Slow Difficulty Needs Help Can not
6. Finger Tap	0 1 2 3 4	Normal Mild reduction Moderately impaired Severely impaired Barely Able	**13. Stability**	0 1 2 3 4	Normal Retrosternal Would fall Loses balance Unable alone
7. Hand Movement	0 1 2 3 4	Normal Mild reduction Moderately impaired Severely impaired Barely Able	**14. Bradykinesia**	0 1 2 3 4	None Minimal Mild abnormality Moderate slowness Marked slowness

APPENDIX 7

Prescription Drug Use by Participants with PD

Antiparkinsonian Drugs

	ID	BH	CA	PE	EN	OR	SE	MA	PR	RO	SI	BR	AM
Laboratory Sample	1							*					
	2			*				*					
	3										*		
	4										*		
	5	*						*					
	6												
	7										*	*	
Home Sample	204				*						*		*
	205		*		*		*	*			*		
	206	*			*		*	*					*
	207	*							*		*		
	211		*								*		
	212				*						*		
	213									*			
	216	*							*		*		
	218		*		*			*			*		
	220									*	*		
	221									*	*		
	224									*	*		
	227							*		*			*
	229									*	*		
	230					*	*				*		
	232									*			
	233			*				*					
	234		*								*		
	235			*	*			*					
	237										*		
	238							*					
	240		*								*		
	281									*			

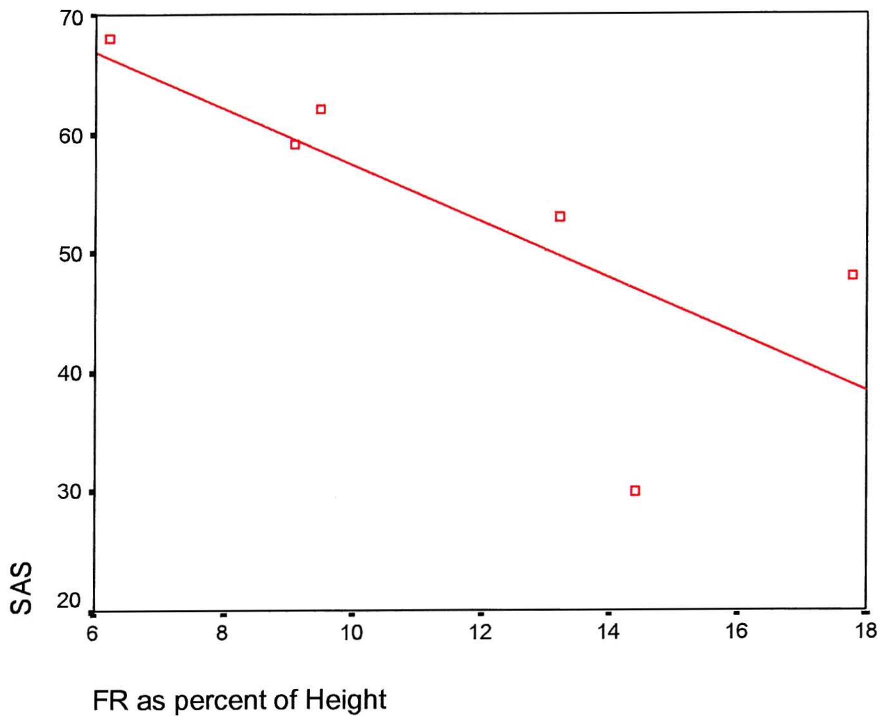
BH = Benzhexol Hydrochloride, **CA** = Cabergoline, **PE** = Pergolide, **EN** = Entacapone, **OR** = Orphenadrine Hydrochloride, **SE** = Selegiline Hydrochloride, **MA** = Madopar, **PR** = Pramipexole, **RO** = Ropinirole, **SI** = Sinemet, **BR** = Bromocriptine, **AM** = Amantadine Hydrochloride.

Other Drugs

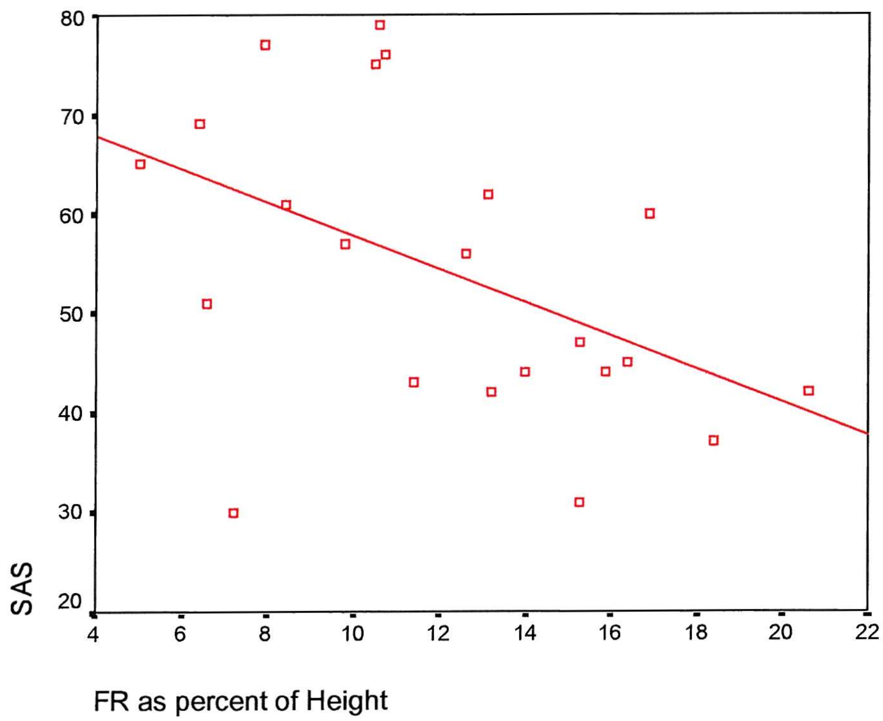
	ID	GIT	CVS	CNS	ES	P	MSD	GUS	RS
Laboratory Sample	1								
	2		****						
	3			*					
	4		*	**					
	5		***						
	6		***		*				
	7			*		*	*		
Home Sample	204	*	*						
	205								
	206								
	207								
	211	*	*						
	212	*				*			
	213			*					
	216								
	218			**					
	220					*			*
	221								
	224		***						
	227	**		*				*	
	229							*	
	230			*					**
	232			*			**		
	233			****					
	234	*		*					
	235			*					
	237		**			*			
	238					*			
	240								
	281								

GIT = Gastro-intestinal Tract, **CVS** = Cardio-vascular System Drugs, **CNS** = Central Nervous System Drugs (including antidepressants in red), **ES** = Endocrine System Drugs, **P** = Pain Drugs, **MSD**= Musculo-skeletal System Drugs, **GUS**= Genito-urinary System, **RS**= Respiratory System.

APPENDIX 8



70
60
50
40
30
20
SAS
6
8
10
12
14
16
18
FR as percent of Height



80
70
60
50
40
30
20
SAS
4
6
8
10
12
14
16
18
20
22
FR as percent of Height

APPENDIX 9

Main Study Sample Size Calculation

The power of a test is 'the probability that a study of a given size would detect as statistically significant a real difference of a given magnitude' (Altman, 1994). It was necessary to calculate a sample size for comparing two, independent groups (people with and without PD). The graphical method based on the standardized difference was used to make the calculation, as recommended by Altman. The variable on which the sample sizes were calculated was the number of steps taken to turn 180°: data had been collected on this variable (part of the SS-180, too) in previous studies. In calculating the sample size, it was necessary to specify:

- The standard deviation of the variable
- The clinically relevant difference
- The significance level, and
- The power

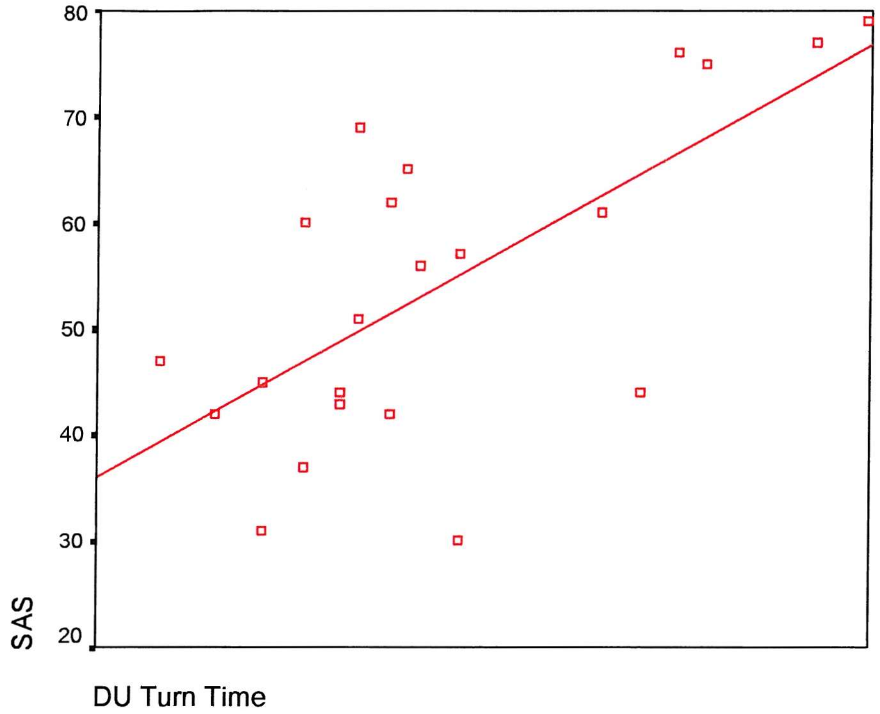
Thigpen et al (2000) found that elderly people took a mean 3.6 steps to turn 180° during the 'Timed Up and Go' test. As the raw data were presented, the sample mean number of turning steps and the associated standard deviation could be calculated. During a previous study (Ashburn et al, 2001) we found that people with PD took a mean 5.9 turning steps. Their work was based on the number of steps taken during a functional 180° turn: of 41 people with PD studied, 63% reported difficulty turning. Although the outcome measure in both studies was the number of steps taken during a 180° turn, the conditions under which the data were collected were quite different. They were, however, the nearest approximation available on which to base the sample calculation.

The relevant difference in means was 2.3. The standardized difference was the ratio of the relevant difference (2.3) to the standard deviation (1.9), i.e. 1.2. With this difference, 80% power at the 5% significance level would be achieved with a sample size of 22, i.e. 11 in each group. The power calculation was repeated using a relevant difference of 2 *whole* steps rather than 2.3 (giving a standardized difference of 1.1); 80% power at the 5% significance level would be achieved with 14 people in each group.

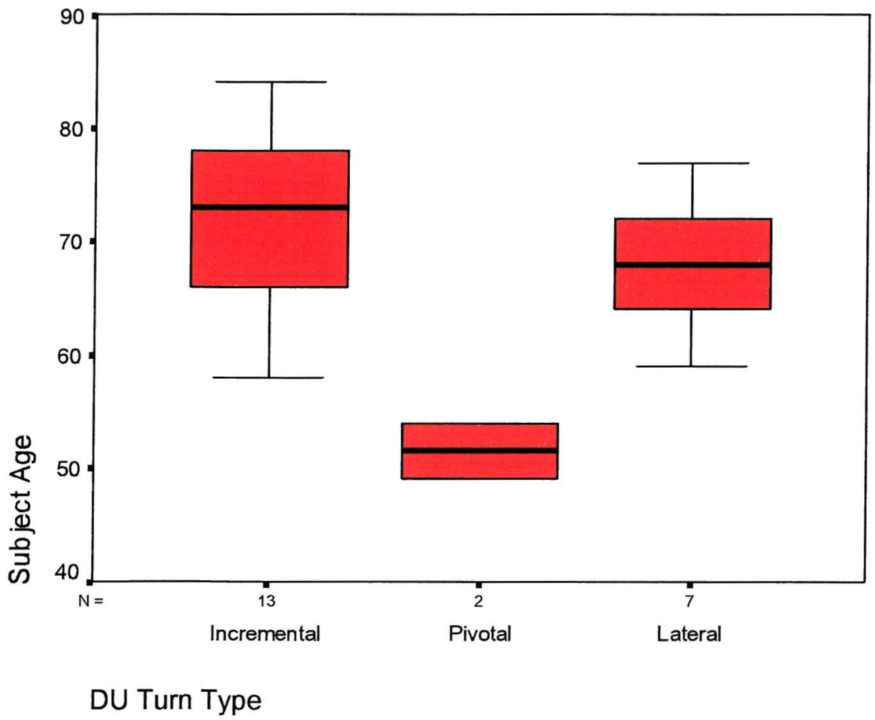
APPENDIX 10

The SS-180 and its correlates: illustrative examples

DU Turn Time *v* SAS in People with PD: $r_s = 0.687$, $P = 0.000$



DU Turn Type *and* Age in People with PD: P = 0.047



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Aita J (1982). Why patients with Parkinson's Disease fall. *Journal American Medical Association* 238: 515-516

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