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**Correlations of Balance and Gait Measures with the
UPDRS and with Each Other**

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**Correlations of Balance and Gait Measures with the
UPDRS and with Each Other**

by

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Dedication

This thesis is dedicated to the amazing participants in this study and to the memory of
Bobbie Elliott, Abraham Hsie and William (Bill) Heath.

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Correlation of Balance and Gait Measures with the UPDRS and with Themselves

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Abstract: The purpose of the study was to determine whether a) current balance and gait measures correlate with the Unified Parkinson's Disease Rating Scale (UPDRS) total and motor scores; b) performance and self-perceived measures of balance correlate; c) instrumented and non-instrumented over ground measures of gait variables are related. We recruited 89 subjects with mild to moderate Parkinson's disease (PD), 65 male, mean age 69.73 ± 8.18 years, mean time since onset 8.25 ± 5.23 years, to perform balance and gait tests. Patients walked forward at usual and fast speeds and backwards on the instrumented walkway, performed timed tests of balance and walking over ground, as well as the Gait and Balance Scale (GABS), and the UPDRS while ON & OFF PD medications. Subjects also rated balance confidence. Spearman's rho correlations were calculated for each balance and gait parameter and the UPDRS, for performance and self-perceived balance measures, and for gait parameters walking on the instrumented walkway and over ground. Paired t-tests were performed in both medications states to compare means for the gait variables on the instrumented walkway and over ground. We

found that the postural instability gait dysfunction index (PIGD) was the only balance or gait measure to correlate with the UPDRS total score exclusively off PD medications. None of the other balance or gait measures were significantly associated with the total or motor section scores of the UPDRS. The performance balance measures were strongly related to the self- perceived balance measures and with each other. The strongest correlations between instrumented and non-instrumented walking were for velocity walking fast forward, both ON & OFF PD medications, and for stride length walking backward both ON & OFF PD medications. Means for velocity walking forward and fast forward, cadence walking forward, and stride length walking backward were significantly higher on the instrumented walkway than over ground without instrumentation. Cadence walking backward was higher over ground ON & OFF PD medications. We concluded that dynamic tests of balance and walking probably are measuring constructs different than the UPDRS. While performance and self-perceived tests of balance correlate strongly, it is probably necessary to measure both. Instrumented and over ground walking need further study.

TABLE OF CONTENTS

List of Tables	x
List of Figures	xxi
List of Abbreviations	xxii
Chapter 1 SPECIFIC AIMS AND PROBLEM STATEMENT	1
Chapter 2 BACKGROUND AND SIGNIFICANCE	9
Unified Parkinson’s Disease Rating Scale.....	10
Measuring Balance in Parkinson’s Disease – Use of Balance Measures Developed for the Elderly Population	22
Self-Perceived Measures of Balance	35
Measuring Balance Using Walking Tasks.....	38
Self-Perceived Measures of Walking.....	42
Walking Parameters and Balance/Falls Risk	44
Comfortable Walking Speed.....	53
Fast Walking Speed/Maximal Walking Speed	58
Backward Walking.....	61
Turning.....	63
Parkinson’s disease Specific Balance & Gait Measures.....	65
Selection of Evaluation Measures.....	68
Falls Risk Measurement.....	72
Selecting an Evaluation Measure Across the Continuum of Parkinson’s Disease.....	82
Chapter 3: METHODS	97
Subjects	98
Measures	99
Testing Protocol.....	106
Statistical Analysis.....	108
Chapter 4 RESULTS.....	1166

Reliability of Data.....	1244
Specific Aim 1	1255
Hypothesis 1:.....	1255
Hypothesis 2 :.....	1288
Hypothesis 3:.....	1299
Hypothesis 4:.....	1766
Summary Results of Specific Aim 1.....	1777
Specific Aim 2	1788
Summary Results Specific Aim 2	1922
Specific Aim 3	1922
Walking Forward Usual Speed	1922
Walking Forward at a Fast Speed	2022
Walking Backward.....	2066
Summary Specific Aim 3	2111
Chapter 5 DISCUSSION	2211
Specific Aim 1	2211
Hypothesis 1: Performance on the Balance Measures	2211
Hypothesis 1: Correlations of the Balance Measures with the UPDRS.....	2288
Hypothesis 2: Performance on Balance Measures & UPDRS Motor Section	2377
Hypothesis 2: Correlations of the Balance Measures with the UPDRS Motor Section:	2388
Hypothesis 3: Performance of Gait Measures and UPDRS Total Score	2388
Hypothesis 3: Correlations of Gait Parameters with the UPDRS Total Score.....	2522
Hypothesis 3: Correlations of the Gait Variables with each Other.....	2544
Hypothesis 4: Correlations of Gait Parameters with the UPDRS Motor Section	2566
Specific Aim 2	2588
Correlations of Performance Based and Self-Perceived Balance Tests.....	2588

Correlations of Balance Measures ON & OFF PD Medications	2633
Correlations between PIGD index and GABS ON & OFF PD Medications.....	2644
Correlations between the 5 Step Test and Turning 360 Degrees ON & OFF PD Medications:	2688
Correlations between Turning 360 Degrees to the Right and Left:	2699
Specific Aim 3	27070
Walking Forward Usual Speed	2722
Walking Forward at a Fast Speed	2788
Walking Backward.....	2799
Limitations to the Study.....	2844
Chapter 6 CONCLUSIONS & FUTURE DIRECTIONS	2866
Appendix A: UNIFIED PARKINSON’S DISEASE RATING SCALE	2922
Appendix B GAIT AND BALANCE SCALE (GABS).....	3011
Appendix C The Activities-specific Balance Confidence (ABC) Scale*	3055
References.....	3066
Vita.....	3299

List of Tables

Table 1: Reliability and Minimal Detectable Change for Existing Balance & Gait Measures	70
Table 2: Sensitivity and Specificity of Measures	71
Table 3 Difference in Types of Falls between Patients with PD who Fall and Healthy Control Subjects (modified after Bloem 2001).....	74
Table 4: Difference in Performance in Common Balance and Gait Measures in Persons with PD who Fall and Healthy Control Subjects who Do Not Fall	78
Table 5: Differences between PD Patients Who Fall and Do Not Fall on Balance & Gait Tests	79
Table 6: Difference between PD Patients Who Fall & Do Not Fall on Higher Level Balance & Gait Tests.....	79
Table 7: Differences between Recurrent and Non-recurrent Fallers in PD	80
Table 8: Studies on Differences in Gait Parameters in Parkinson's disease ON & OFF PD Medications	81
Table 9: Differences in Dynamic Balance Measures ON & OFF PD Medications (Modified from Bryant et al. 2008).....	81

Table 10: Correlation between Balance and Gait Measures	89
Table 11: Comparison of Items between Balance and Gait Measures.....	91
Table 12: Demographic Information Subjects from Galveston & Houston	1188
Table 13: Demographic Variables Related to Parkinson’s Disease.....	1199
Table 14a: ANOVA Demographic Variables	12020
Table 14b: Post Hoc Testing Demographic Variable	1211
Table 14c: Falls Categories across Sites	1211
Table 14d: Kruskal-Wallis Tests Demographic Data	1222
Table 15: Associated Medical Conditions Galveston and Houston (%).....	1222
Table 16: Parkinson’s Disease Medications Galveston and Houston (%).....	1233
Table 17: Non-Parkinson’s Disease Medications Galveston and Houston (%)	1233
Table 18: Reliability Data (Intra class Correlation Coefficient).....	1244
Table 19: Descriptive Statistics Balance Measures and UPDRS All Sites.....	1277
Table 20a: Correlations of Balance Tests with the UPDRS Total Score.....	1277
Table 20b: Significant Correlations between Balance Measures	1288

Table 21a: Correlations of Balance Measures with UPDRS Motor Score	13030
Table 21b: Significant Correlations between Balance Measures & UPDRS Motor Score (excluding those already presented in Table 20b)	13030
Table 22: Regression Analysis for Balance Measures and UPDRS OFF Medications.....	1311
Table 23: Regression Analysis for Balance Measures and UPDRS ON Medications.....	1311
Table 24 a: Descriptive Statistics Galveston Walking Forward Usual Speed.....	134
Table 24b: Descriptive Statistics VA Group 1 Walking Forward Usual Speed.....	135
Table 24c: Descriptive Statistics VA Group 2 Walking Forward Usual Speed	1366
Table 24d: Descriptive Statistics Galveston VA Group 2 Walking Forward Usual Speed.....	137
Table 24e: Galveston Paired T-Tests Gait Parameters Walking ON & OFF PD Medications.....	1388
Table 24f: VA Group 1 Paired T-Tests Gait Parameters Walking ON & OFF PD Medications.....	138
Table 24g: VA Group 2 Paired T-Tests Gait Parameters Walking ON & OFF PD Medications.....	1399

Table 24h: Galveston VA Group 2 Paired T-Tests Walking ON & OFF PD	
Medications.....	139
Table 25a: Spearman’s Correlations Galveston Gait Parameters Walking Forward	
Usual Speed & UPDRS Total Score	142
Table 25b: Significant Correlations between Gait Parameters Walking Forward	
Usual Speed	143
Table 26a: Spearman’s Rho Correlations VA Group 1 Gait Parameters	
Walking Forward Usual Speed & UPDRS Total Score	143
Table 26b: Significant Correlations between Gait Parameters	144
Table 27a: Spearman’s Rho Correlations VA Group 2 Gait Parameters	
Walking Forward Usual Speed & UPDRS Total Score	144
Table 27b: Significant Correlations between Gait Parameters VA2 Walking	
Forward Usual Speed.....	145
Table 28a: Spearman’s Rho Correlations Galveston & VA Group 2 Gait	
Parameters Walking Forward Usual Speed & UPDRS Total Score..	145
Table 28b: Significant Correlations between Gait Parameters Galveston VA2	
Walking Forward Usual Speed.....	146
Table 29a: Descriptive Information Galveston Walking Fast Forward &	
UPDRS Total & Motor Scores	146

Table 29b: Descriptive Information VA Group 1 Walking Fast Forward & UPDRS Total & MotoScores.....	146
Table 29c: Descriptive Information VA Group 2 Walking Fast Forward & UPDRS Total & Motor Scores	148
Table 29d: Descriptive Information Galveston VA Group 2 Walking Fast Forward and UPDRS Total & Motor Scores	149
Table 29e: Paired T-Tests Gait Velocity Walking Fast Forward ON & OFF PD Medications.....	150
Table 30a: Spearman's Rho Correlations Velocity Galveston Walking Fast Forward & UPDRS Total & Motor Scores	155
Table 30b: Significant Correlations between Gait Parameterers Galveston Walking Fast Forward	155
Table 31a: Spearman's Rho Correlations Velocity VA Group 1 Walking Fast Forward & UPDRS Total & Motor Scores.....	156
Table 31b: Significant Correlations between Gait Parameters VA Group 1 Walking Fast Forward.....	156
Table 32a: Spearman's Rho Correlations Velocity VA Group 2 Walking Fast Forward & UPDRS Total & Motor Scores	157

Table 32b: Significant Correlations between Gait Parameters VA Group 2 Walking FastForward.....	158
Table 33a: Spearman's Rho Correlations Velocity Galveston VA Group 2 Walking Fast Forward & UPDRS Total & Motor Scores.....	158
Table 33b: Significant Correlations between Gait Parameters Galveston VA Group 2 Walking Fast Forward.....	159
Table 34a: Descriptive Statistics Galveston Walking Backward & UPDRS Total & MotorScores.....	163
Table 34b: Descriptive Statistics VA Group 1 Walking Backward & UPDRS Total & Motor Scores	164
Table 34c: Descriptive Statistitcs VA Group 2 Walking Backward & UPDRS Total & Motor Scores	165
Table 34d: Descriptive Statistics Galveston VA Group 2 Walking Backward & UPDRS Total & Motor Scores	166
Table 34e: Paired T-Tests Velocity Walking Backward ON & OFF PD Medications	167

Table 34f: Paired T-Tests Cadence Walking Backward ON & OFF PD	
Medications.....	168
Table 34g: Paired T-Tests Stride Length Walking Backward ON & OFF PD	
Medications	169
Table 35a: Spearman's Rho Correlations Galveston Walking Backward & UPDRS	
Total & Motor Scores.....	170
Table 35b: Significant Correlations between Gait Parameters Galveston Walking	
Backward	171
Table 36a: Spearman's Rho Correlations VA Group 1 Walking Backward &	
UPDRS Total & Motor Scores	172
Table 36b: Significant Correlations between Gait Parameters VA Group 1 Walking	
Backward.....	
1722	
Table 37a: Spearman's Rho Correlations VA Group 2 Walking Backward &	
UPDRS Total & Motor Scores.....	173
Table 37b: Significant Correlations between Gait Parameters VA Group 2	
Walking Backward	174

Table 38a: Spearman’s Rho Correlations Galveston VA Group 2 Walking & Backward & UPDRS Total & Motor Scores	174
Table 38b: Significant Correlations between Gait Parameters Galveston VA Group 2 Walking Backward	175
Table 39a: Spearman’s Rho Correlations Galveston Walking Forward Usual Speed & UPDRS Motor Score	18080
Table 39b: Significant Correlations between Gait Parameters VA Group 1.....	180
Table 40a: Spearman's Rho Correlations VA Group 1 Walking Forward Usual Speed & UPDRS Motor Score.....	181
Table 40b: Significant Correlations Gait Parameters VA Group 1	181
Table 41a: Spearman’s Rho Correlations VA Group 2 Walking Forward Usual Speed & UPDRS Motor Section.....	1822
Table 41b: Significant Correlations between Gait Parameters VA Group 2	182
Table 42a: Spearman’s Rho Correlations Galveston VA Group 2 Walking Forward Usual Speed & UPDRS Motor Section.....	1833
Table 42b: Significant Correlations between Gait Parameters Galveston VA Group 2	183
Table 43a: Spearman’s Rho Correlations Galveston Walking Backward and UPDRS Motor Section.....	1844

Table 43b: Significant Correlations between Gait Parameters Galveston Walking Backward	1855
Table 44a: Spearman’s Rho Correlations VA Group 1 Walking Backward & UPDRS Motor Section.....	1855
Table 44b: Significant Correlations between Gait Parameters VA Group 1.....	186
Table 45a: Spearman’s Rho Correlations VA Group 2 Walking Backward & UPDRS Motor Section.....	1866
Table 45b: Significant Correlations between Gait Parameters VA Group 2 Walking Backward	1877
Table 46a: Spearman's Rho Correlations Galveston VA Group 2 Walking Backward & UPDRS Motor Section.....	187
Table 46b: Significant Correlations between Gait Parameters Galveston VA2 Group Walking Backward	18888
Table 47: Descriptive Statistics Performance-Based and Self-perceived Balance Measures	18888
Table 48a: Spearman's Rho Correlations Performance-Based & Self-Perceived BalanceMeasures.....	189
Table 48b: Significant Correlations between Performance-Based & Self- Perceived Balance Measures	190

Table 49: Descriptive Statistics Velocity All Sites Walking Forward Usual	
Speed	195
Table 50: Paired T-Tests Velocity All Sites Walking Forward Usual Speed.....	196
Table 51: Descriptive Statistics Cadence All Sites Walking Forward Usual	
Speed.....	197
Table 52: Paired T-Tests Cadence All Sites Walking Forward Usual Speed.....	198
Table 53: Descriptive Statistics Stride Length All Sites Walking Forward	
Usual Speed	199
Table 54: Paired T-Tests Stride Length All Sites Walking Forward Usual	
Speed.....	200
Table 55: Descriptive Statistics All Sites Walking Fast Forward	204
Table 56: Paired T-Tests Velocity All Sites Walking Fast Forward	2055
Table 57: Descriptive Statistics Velocity All Sites Walking Backward.....	2077
Table 58: Paired T-Tests Velocity All Sites Walking Fast Forward.....	208
Table 59: Descriptive Statistics Cadence All Sites Walking Backward.....	2133
Table 60: Paired T-Tests Cadence All Sites Walking Backward.....	214
Table 61: Descriptive Statistics Stride Length All Sites Walking Backward.....	2166
Table 62: Paired T-Tests Stride Length All Sites Walking Backward	2177

Table 63: Summary of T-tests and Correlations between Walking on the GAITRite and Over Ground	21919
Table 64: Key Findings.....	22020

List of Figures

Figure 1: Velocity Walking Forward GAITRite vs. Over Ground and OFF vs. ON Medications.....	20101
Figure 2: Cadence Walking Forward GAITRite vs. Over Ground and OFF vs. ON Medications.....	20101
Figure 3: Stride Length Walking Forward GAITRite vs. Over Ground OFF vs. ON Medications.....	20202
Figure 4: Velocity Walking Fast Forward GAITRite vs. Over Ground OFF vs. ON Medications.....	20909
Figure 5: Velocity Walking Backward GAITRite vs. Over Ground OFF vs. ON Medications.....	20909
Figure 6: Cadence Walking Backward GAITRite vs. Over Ground OFF vs. ON Medications.....	21515
Figure 7: Stride Length Walking Backward GAITRite vs. Over Ground OFF vs. ON Medications	21818

List of Abbreviations

UTMB	University of Texas Medical Branch
VA	Michael E. DeBakey Veteran's Administration Hospital
GSBS	Graduate School of Biomedical Science
PD	Parkinson's disease
UPDRS	Unified Parkinson's Disease Rating Scale
UPDRSM	Unified Parkinson's Disease Rating Scale Motor Section
H&Y	Hoehn & Yahr Scale
MDS	Movement Disorder Society
ADL	Activities of Daily Living
BMI	Body Mass Index
PASE	Physical Activity Scale for the Elderly
CES-D	Center for Epidemiology Studies Depression Scale
PPT	Physical Performance Test
mPPT	Modified Physical Performance Test
SPPB	Short Physical Performance Battery
OARS	Older Americans Resource Services Disability Scale
PADL	Performance Test of Activities of Daily Living
TEA	The Everyday Attention Scale
GES	Gait Efficacy Scale
mGES	Modified Gait Efficacy Scale
CS-PFP	Continuous Scale Physical and Functional Performance Test

ABC	Activities Specific Balance Confidence Scale
FES	Falls Efficacy Scale
GABS	Gait & Balance Scale
PIGD	Postural Instability Gait Dysfunction Index
BBS	Berg Balance Scale
FRT	Functional Reach Test
POMA	Performance Oriented Mobility Assessment
TUG	Timed Up and Go
FAR	Functional Axial Rotation
PROFILE PD	Profile of Function and Impairment Level Experience Parkinson's Disease
SOT	Sensory Organization Test
TMT	Timed Motor Test
CWS	Comfortable Walking Speed
FWS	Fast Walking Speed
MWS	Maximal Walking Speed
FGA	Functional Gait Assessment
DGI	Dynamic Gait Index
6MWT	6 Minute Walk Test
2MWT	2 Minute Walk Test
DLST	Double Limb Support Time
SLST	Single Limb Support Time

COP	Center of Pressure
COBM	Center of Body Mass
BOS	Base of Support
ICC	Intra class Correlation
ROC	Receiver Operated Characteristic Curve

Chapter 1 SPECIFIC AIMS AND PROBLEM STATEMENT

Parkinson's disease is a neurodegenerative disease of the central nervous system where dopamine, a neurotransmitter found in the substantia nigra is depleted over time, resulting in the cardinal symptoms of PD- tremor at rest, rigidity, bradykinesia or slowness of movement and postural instability (Hou et al. 2008). Patients with PD have difficulty with well-learned sequences of movement, for example walking, speaking, writing, and making facial expressions and gestures. There are one million people with PD in the United States, and 7-10 million persons with PD world-wide (National Parkinson's Disease Foundation 2012). Sixty thousand new cases are diagnosed in the USA each year (National Parkinson's Disease Foundation, 2012). Males are 1.5 times more likely to contract the disease than females (National Parkinson's Disease Foundation 2012). The cost of PD in the United States is \$25 billion dollars per year; medications for each person with PD can cost up to \$2500, and a single deep brain stimulation surgery costs \$100,000 (Parkinson's Disease Foundation 2012). There is no cure for PD; however current treatments include dopamine replacement medications, deep brain stimulation implant surgery, as well as physical, occupational, and speech therapies (Hou, 2008).

The disease progresses differently for each individual with PD. Tremor is often the first symptom noticed, but almost as often the person experiences difficulty with walking or balancing (Hou et al. 2008). Usually the disease starts on one side of the body, progresses to the second side, and then spreads to the trunk. Postural responses begin to deteriorate, walking becomes more difficult, and risk for falls begins. Falls happen during common daily activities specifically, walking, turning when walking, or transferring from sitting to standing (Bloem et al. 2001). Gradually the ability to generate motor responses to meet mobility and self-care demands is compromised and

independence is lost. Eventually walking becomes too unsteady and poses a falls risk or becomes too energy demanding to be functional, and the patient is forced to use a wheelchair for mobility. The non-motor symptoms of PD, for example sleep dysfunction, eating dysfunction, constipation, bladder and/or bowel dysfunction, orthostasis, fatigue, cognitive dysfunction (short term memory deficits, executive dysfunction, and eventually dementia), and mood dysfunction (depression, anxiety or apathy), coincide with the motor symptoms, further challenging the ability to perform basic and instrumental activities of daily living independently (Hou et al. 2008).

Evaluation is necessary to follow disease progression, monitor the effect of medications on symptoms, examine the degree to which therapy improves performance, plan therapy interventions to optimize the client's abilities and participation, and finally to examine the effects of research protocols. It is challenging to evaluate patients with PD, first because there is considerable variability between subjects, and second because an individual's performance can vary dependent on where they are in the medications cycle (Sarwar et al. 2008). Some patients experience motor fluctuations such that performance is optimal approximately one hour after dopamine medications is ingested, and deteriorates as the medications' effects wear off, often within 4-5 hours early in the disease, and 2-3 hours later on in the disease (Hou et al. 2008). There are clients who experience dyskinesias or involuntary non-purposeful extraneous movements caused by the medications that can interfere with function. Dyskinesias can affect the face, mouth, torso and extremities and can be embarrassing for the patient in work or social situations. Given the progressive nature of PD, evaluation instruments need to change in order to be responsive to symptoms over the continuum of the disease.

Motor fluctuations give rise to an important question, whether the patient should be evaluated when at peak medications performance or whether a patient should be

evaluated when the medications wear off and performance deteriorates. Evaluating the patient in the OFF medications state measures true disease status, whereas evaluating the patient in the ON medications state measures the effect of the medications on function. Typically the patient is evaluated when medication is optimal, but is there a need to evaluate the client in both medication states? Will the patient need to learn different strategies to manage the disease when medication is at its peak and when medication is depleted? Will the risk for falling be different in the ON & OFF PD medications state? Is evaluation more accurate in the ON versus OFF state?

The Unified Parkinson's Disease Rating Scale (UPDRS) is the gold standard evaluation tool for evaluating disease severity in Parkinson's disease (Movement Disorders Society 2003). The UPDRS measures cognition and behavior in section I, activities of daily living function in section II, motor function in section III and complications of therapy in section IV. The first three sections of the instrument use a 5 point ordinal scale of 0-4, where higher scores indicate worse performance. The UPDRS measures the major impairments of PD, specifically tremor, rigidity and bradykinesia; however it gives minimal attention to functional balance and gait, with a single question devoted to each. The section on complications of therapy is scored primarily with a yes/no dichotomy and focuses on dyskinesia, dystonia, sleep and eating disorders, and vasomotor dysfunction (like orthostasis) (Stebbins et al. 1998). A newer version of the UPDRS, the Movement Dysfunction Society Unified Parkinson's Disability Rating Scale was presented and tested psychometrically in 2008; however it was not available at the beginning of the study. There has been considerable criticism of the UPDRS for its focus on impairment rather than on function and participation (Dibble et al. 2008; Schenkman et al. 2010). Others have criticized the single item on balance, retropulsion, which measures reactive static balance to a pull threat rather than the predictive dynamic feed

forward balance needed to move in a changing environment (Dibble 2006; Dibble et al. 2008; Schenkman et al. 2011). Similarly, the item on gait is insufficient because it too focuses on walking as an isolated task, in a fixed environment, over a limited distance, rather than walking in changing surroundings at a variety of speeds, often while performing a second task simultaneously (talking or carrying something) (Foreman et al. 2010; Schenkman et al. 2011). The UPDRS does not provide the therapist with the critical information needed to design a therapeutic intervention to optimize the client's function. Physical therapy cannot impact tremor, rigidity and bradykinesia, symptoms that are over-represented on the UPDRS. Therapists need information on many other functional abilities: bed mobility, mobility in a wheelchair, balance in sitting standing walking and during transfers, ambulation on a variety of surfaces at varying speeds often while performing additional tasks simultaneously, ascent and descent of stairs and inclines, and exercise tolerance and fitness. Fatigue, sleepiness, perception of falls risk, depression, and activity level all have important implications for developing a therapy plan of care and need to be evaluated. What other examinations and evaluations are therapists using to measure these parameters, and to what degree do they correlate with the UPDRS?

There are two types of measures, namely performance and self-report/self-perception. It has been suggested that individuals with PD initially under-estimate their limitations and later on in the disease over-rate their disability (Shulman et al. 2006). How well do performance measures of balance correlate with self-reported confidence in mobility? Is there an association between confidence in mobility and walking performance? Are there particular parameters of gait that are related to confidence in mobility? Does direction the client is walking matter when considering the association of gait parameters with confidence in mobility?

While gait can be measured using computerized walkways in the lab, such devices are impractical in a fast paced physical therapy clinic. It would be helpful to know to what degree measurements of gait velocity, cadence, and stride length, measured on an instrumented walkway like the GAITRite (Cir, Havertown PA,) correlate with the same parameters measured when walking over ground in a non-instrumented situation. Is sophisticated instrumentation a necessity for gait evaluation in PD or are clinical measures sufficient? Does speed of gait, direction of walking, or medication state make a difference in the association between instrumented and non-instrumented gait analysis?

The purpose of this study was first, to determine the degree to which specific measures of gait and balance correlate with the Unified Parkinson's Disease Rating Scale (UPDRS), and second to determine whether specific balance as well as gait measures correlate with each other.

Specific aim 1 was to determine which clinical measures of balance and gait in PD correlate, both ON & OFF PD medications, with the UPDRS total score and the UPDRS motor score, since the UPDRS is the gold standard measure of disease progression.

Our *first hypothesis* was that there would be a positive relationship (Spearman $r > 0.70$) between the 5 step test, timed 360 degree turns, PIGD index and the gait and balance scale (GABS) with the total score of the UPDRS both ON & OFF PD medications.

Our *second hypothesis* was that there would be a positive relationship (Spearman $r > 0.70$) between the 5 step test, timed 360 degree turns, PIGD index and the GABS, with the motor score of the UPDRS both ON & OFF PD medications.

Our third hypothesis was that there would be a negative relationship (Spearman's $\rho \leq 0.70$) between GAITRite and over ground measures of velocity, cadence and stride length walking forward, fast forward and backward with the total score of the UPDRS, both ON & OFF PD medications.

Our fourth hypothesis was that there would be a negative correlation (Spearman's $\rho \leq 0.70$) between GAITRite and over ground measures of velocity, cadence and stride length, walking forward, fast forward, and backward, with the motor section score of the UPDRS, both ON & OFF PD medications.

Specific aim 2 was to determine the degree to which performance and self-perceived measures of balance used for patients with PD correlated with each other, both when the patient was ON & OFF PD medications.

Our hypothesis was that there would be a negative relationship (Spearman $r < 0.70$) between self-perceived measures of balance (Activities Specific Balance Confidence Scale (ABC) and performance measures of balance (5 step, timed 360 degree turning, PIGD index, and GABS,) both when the patient was ON & OFF PD medications. Additionally we investigated the correlation between the 4 performance based balance measures (5 step test, timed 360 degree turning, PIGD index, and the GABS) to determine whether there were any measuring a similar construct, again both ON & OFF PD medications. If measures were highly correlated then perhaps only one needs to be performed so as to cut down on limited time for clinical evaluation.

Specific aim 3 was to determine the degree to which instrumented walkway measures of gait (velocity, cadence, and stride length) correlated with non-instrumented over ground measures of the same gait parameters, first with the patient walking forward

at a usual pace, second walking forward at a fast pace and third walking backward at a comfortable and safe pace, both ON & OFF PD medications.

Hypothesis 1a was that there would be no significant difference in the means for each gait parameter (velocity, cadence, & stride length) measured walking forward at a usual speed on the GAITRite and over ground, both ON & OFF PD medications.

Hypothesis 1b was that the Spearman's rho correlations for each gait parameter (velocity, cadence, & stride length) made walking forward at a usual speed on the instrumented GAITRite and over ground would be ≥ 0.70 both ON & OFF PD medications.

Hypothesis 2a was that there would be no significant difference in the means for each gait parameter (velocity, cadence, & stride length) made walking forward at a fast speed on the instrumented GAITRite and over ground, both ON & OFF PD medications.

Hypothesis 2b was that the Spearman's rho correlations for each gait parameter (velocity, cadence, & stride length) made walking forward at a fast speed on the instrumented GAITRite and over ground would be ≥ 0.70 both ON & OFF PD medication.

Hypothesis 3a was that there would be no significant difference in the means for each gait parameter (velocity, cadence, & stride length) made walking backward at a comfortable speed on the instrumented GAITRite and over ground, both ON & OFF PD medications.

Hypothesis 3b was that the Spearman's rho correlations for velocity, cadence, and stride length made walking backward at a safe speed on the instrumented GAITRite (Cir Corp, Havertown PA) and over ground both ON & OFF PD medications would be > 0.7 with alpha set at 0.05.

Chapter 2 BACKGROUND AND SIGNIFICANCE

Parkinson's disease (PD) is a neurodegenerative disease of the central nervous system characterized by some or all of the symptoms of rigidity, tremor at rest, bradykinesia (slowness of movement), and postural instability (Lang 1998). Parkinson's disease affects about 1 million people in the United States; however this number is expected to increase with the aging of the American population (Parkinson's Disease Foundation 2010). It is estimated that 0.6% of the population between 65 and 79 suffer from PD, and 3% of the population over the age of 80 is diagnosed with PD by a physician (Parkinson's Disease Foundation 2010). Subjects with PD walk with slow shuffling steps, have episodes of freezing or festination of gait, have difficulty initiating walking, turning, and walking in confined spaces, and show worsening of gait parameters when they perform a second task simultaneously, for example talking or carrying an object (Morris et al. 1996a; Morris et al. 1998; Morris et al. 1999; Schaafsma et al. 2003; Hausdorff et al. 2005; Morris et al. 2006; Morris 2006; Rochester et al. 2008; Morris et al. 2010). Associated symptoms of PD include speech disturbances (Trail, et al. 2005), dysphagia or swallowing dysfunction (Monte et al. 2005), micrographia (small handwriting), sleep disturbances (Scaravilli et al. 2003), depression (Weintraub 2005), apathy (Zgaljardic et al. 2003), autonomic dysfunction (Kenny 2001), and cognitive impairment (Zgaljardic et al. 2003; Muslimovic et al. 2005). Given the multi-dimensionality of the disease, impairments and functional limitations, the progressive disability, and the resultant physical, emotional, and social consequences of PD, it is difficult to develop a comprehensive evaluation tool.

Accurate assessment of the patient with PD at any stage of the disease is essential both for formulating appropriate treatment plans, for scientific research measuring the

preclinical and clinical symptoms of the disease, or studying the effects of emerging pharmacological and rehabilitation therapeutic interventions (Sarwar et al. 2008). Instruments that are reliable, valid, and easy to administer, that comprehensively reflect the patient's status across the disease spectrum, are essential for practice and research. Currently there are assessment tools that aim to measure body systems impairment, functional limitations, challenges for participation in life roles and quality of life (Sarwar et al. 2008). While it would be ideal if there were a single instrument to measure the full spectrum of the disease manifestations, such an evaluation would likely be too long to administer within the constraints of time for patient examination. Hence the clinician is forced to choose the evaluation tool that best meets the need at hand. It is difficult to collect accurate, reliable, and valid data in patients with PD because medication fluctuations alter impairments, function, and disability, within a given day, or across repeated testing. There is a paucity of longitudinal data in PD because of disease progression and the alteration of medications as the disease evolves (Sarwar et al. 2008).

UNIFIED PARKINSON'S DISEASE RATING SCALE

The majority of examination and evaluation tools available today focus on the motor disability, (particularly gait and postural stability including risk for falls), coordination of movement, and functional status (Nutt 2005). The Unified Parkinson's Disease Rating Scale (UPDRS), the most widely used and well-known scale, was developed in 1987, and attempts to comprehensively measure individual motor and non-motor signs and symptoms over the course of PD (Fahn et al. 1987). There are 4 sections to the UPDRS: the first mentation, behavior, and mood (cognition, depression, apathy and hallucinations), the second activities of daily living (speech, handwriting, dressing, grooming, and transfers), the third motor skills (tremor, rigidity, posture, balance and

gait), and finally the fourth complications of therapy (dyskinesias, dystonia, motor fluctuations, orthostasis, appetite and sleep). Items are measured on a Likert scale from 0-4 where increasing scores represent increasing disability. The mentation, behavior and mood section has 4 items for a range of scores from 0-16. The ADL section has 13 items for a range of scores from 0-52. The motor section has 14 items, however the arm and leg agility, rigidity, and tremor items are scored individually for each side and different regions of the body, hence the range of scores for this section is 0-108. The total score of the UPDRS consists of the items in sections 1-3 for a range of 0-176. There are 10 items on the complications of therapy section, often rated with yes/no responses, but these items are not included in the total score. Although not part of the UPDRS, it is common to use the Hoehn & Yahr (H&Y) scale and the Schwab and England Activities of Daily Living Scale (SES) concurrently. The original H&Y scale ranged from stages 0-5, where stage 0 implied no signs of disease, and stage 5 referred to someone wheelchair bound or bedridden unless aided. In the modified H&Y scale two new levels were added- stages 1.5 and 2.5. Stage 0 is no signs of disease; stage 1 is unilateral involvement; stage 1.5 is unilateral involvement plus axial involvement; stage 2 is bilateral disease without impairment of balance; stage 2.5 is mild bilateral involvement with recovery on pull test (a test of balance where the client is suddenly pulled backwards and needs to either resist the perturbation or take steps to recover); stage 3 is mild to moderate bilateral involvement, some postural instability, but physically independent; stage 4 is severe disability, still able to walk unassisted with or without an assistive device; and stage 5 is wheelchair bound or bedridden unless aided (Hoehn, 1967). The Schwab and England ADL Scale (SES) examines the degree to which the person with PD is able to perform chores/daily activities, and the amount of difficulty or increased time it takes for their completion. It is scored on a scale of 0%-100% in increments of 10%, where higher

scores indicate greater independence in completing chores (Schwab 1992). The UPDRS, H&Y scale, and SES are attached in appendix A.

The psychometric properties of the UPDRS have been studied extensively. Cronbach's alpha for internal consistency of the UPDRS on medications was 0.96 (Martinez-Martin et al. 1994) and OFF medications was 0.95 (Stebbins et al. 1998). This high internal consistency was maintained across all Hoehn & Yahr stages (stages I & 2= 0.93, stage 3= 0.91, and stages 4 & 5= 0.93 (Stebbins et al. 1998). A second study on internal consistency of the entire UPDRS OFF medications, measured with a Cronbach's alpha, was similar, 0.90 across H&Y stages 2-4 (Steffen 2008). Correlations between the total UPDRS score and individual item scores were moderate to strong (Spearman's rank correlations from 0.60-0.81, $p < 0.001$) for 17 items (5 speech, 9 cutting food, 10 dressing, 11 hygiene, 12 turning in bed, 15 walking, 18 speech, 19 facial expression, 23 finger taps, 24 hand movements, 25 alternating movements of hands, 26 leg agility, 27 arising from a chair, 28 posture, 29 gait, 30 postural stability, and 31 body bradykinesia (Martinez-Martin, et al. 1994).

Inter-rater reliability for the total score of the UPDRS, as measured by Spearman's rank correlations was excellent ($r = 0.98$, $p < 0.001$) and Spearman's rank correlations for individual items ranged from 0.42 to 0.90 (Martinez-Martin et al. 1994). Items with a Spearman's rank correlations greater than 0.80 included: 2 thought disorder, 7 swallowing, 11 hygiene, 13 falling, 22 rigidity, and 30 postural stability. Items with Spearman's correlations between 0.70 and 0.79 included: 1 intellectual impairment, 8 handwriting, 9 cutting food, 10 dressing, 12 turning in bed, 14 freezing, 15 walking, and 27 arising from a chair. Test-item correlations were moderate (Spearman's rank correlations from 0.60-0.69) for 5 items: 3 depression, 18 speech, 24 hand movements, 25 rapid alternating movements, and 29 gait. The Spearman's rank correlations were low

(0.42-0.59) for the following items: 19 facial expression, 20 tremor at rest, 21 postural tremor, 23 finger taps, 26 leg agility, 28 posture, and 31 body bradykinesia) (Martinez-Martin et al. 1994; Steffin et al. 2008). It should be pointed out that many of these items reflect deficits in body systems or impairments of PD.

The inter-rater reliability of the motor section of the UPDRS ON medications was excellent (ICC= 0.95, $p < 0.001$) (Martinez-Martin et al. 1994). Item inter-rater reliability was good to excellent (ICC > 0.83) for the following items: 24 repeated alternating movements, 20 resting tremor, 27 rising from a chair, and 29 gait (Richards et al. 1994). Moderate agreement (ICC between 0.70 and 0.79) was found for the following items: 21 action tremor, 22 rigidity, 28 posture, 30 postural stability, and 31 bradykinesia. Poor agreement (ICC < 0.60) was found for the speech disorder and facial expression items (Richards et al. 1994).

Test-retest reliability for the UPDRS total score as well as section scores was done with intervals averaging 14 days between each testing session. The ICCs for the scores were as follows – total score 0.92, section 1 (mentation behavior and mood) 0.74, section 2 (ADL) 0.85, and section 3 (motor) 0.90 (Siderowf et al. 2002). The average time to apply the UPDRS was 16.95 ± 7.98 minutes (Martinez-Martin et al. 1994).

Criterion related validity was established when patients were on PD medications by correlating the UPDRS total score with the original Hoehn & Yahr Staging Scale ($r = 0.71$, $p < 0.001$). Step wise multiple regression analysis showed that 69% of the variance on the H&Y scale scores was explained by 5 items of the UPDRS: 30 postural stability, 10 dressing, 29 gait, 13 falling, and 12 turning in bed (Martinez-Martin et al. 1994). Discriminant validity was established correlating the UPDRS with two scales devised to measure constructs different than Parkinson's disease - the mini-mental status examination (MMSE) ($r = -0.64$, $p < 0.001$) and the Hamilton Depression Scale (HDS)

($r=0.53$, $p<0.001$) (Martinez-Martin et al. 1994). Convergent validity was evaluated by examining the correlation between the UPDRS total score and two other commonly used Parkinson's disease rating scales- the Schwab and England Scale (SES) ($r=-0.95$, $p<0.001$) and the Intermediate Scale for Assessment of Parkinson's Disease ($r=0.96$, $p<0.001$) (Martinez-Martin et al. 1994). Both the discriminant and convergent validity support the construct validity of the UPDRS.

Factor analysis of the UPDRS when patients were in the ON PD medications state, identified 6 factors that explained 59.61% of the variance in UPDRS total scores: factor 1- mobility of the extremities, factor 2 – stability, gait and general mobility, factor 3- functional ability, factor 4 - tremor, factor 5 - communication /expression, and factor 6 - bradykinesia. The correlations between factors ranged from 0.28 to 0.57, with the exception of factor 4 (tremor) which did not correlate with any other factor (Martinez-Martin et al. 1994). Factor analysis for the motor section of the UPDRS identified 6 factors: factor 1- axial function balance and gait, factor 2- resting tremor, factor 3 - rigidity, factors 4&5- bradykinesia affecting the right and left extremities, and factor 6 action/postural tremor. All factors of the motor section of the UPDRS, with the exception of factor 2, correlated significantly with the H&Y scale and the SES ($p<0.05$) when ON & OFF PD medications (Stebbins et al. 1998).

The Movement Disorder Society Task Force for Rating Scales evaluated the current edition of the UPDRS (UPDRS III) to identify strengths and weaknesses (in anticipation of updating the scale). They identified several strengths of the UPDRS, specifically, its strong reliability and validity, its application across disease stages, its thorough evaluation of motor symptoms of PD, its wide-spread use as an outcome measure for research studies in the USA and overseas, and the availability of a videotape to train new users on scoring the instrument (Movement Disorder Society 2003). The task

force identified many weaknesses of the current UPDRS. The scale is not sensitive enough to detect minimal clinical change in clients with preclinical or early stage disease due to floor effects. Additionally the task force found limited scope for non-motor symptoms (e.g. sleep dysfunction, bladder problems, sexual dysfunction, constipation and other gastrointestinal symptoms, and anxiety), ambiguity of instructions, and failure to comply with cultural sensitivity in the ADL section (assumption that all subjects use utensils to eat). The ADL scale has been criticized because a large number of items included are at the impairment level of the Nagi model of disability rather than the functional limitation level, specifically salivation and sensory complaints (Nagi et al. 1991; Movement Disorder Society 2003), and second because it appears to be covering more than one construct. The MDS task force had 4 recommendations. The first was to develop a new edition of the UPDRS that is culturally sensitive and evaluative across age, gender and racial groups. The second recommendation was to define scores that have clinical meaning that define “minimal, mild, moderate and severe” disease stages. The third recommendation was to identify what change in UPDRS scores represented “minimal clinically relevant change”, and what corresponded to “minimal clinically relevant instrumental change”. The fourth recommendation was to add questions to the new edition on non-motor symptoms, and create an appendix that matches non-motor symptoms with corresponding clinical evaluation tools that optimally measure the severity of each area of dysfunction (Movement Disorder Society 2003).

Since section 3 of the UPDRS is the only section that is scored by having the client perform the task, many neurologists and researchers have used this section exclusively to measure disease severity and progression (Nutt et al. 2005). A criticism of the motor section is that it focuses on deficits in body systems/ impairment (tremor, bradykinesia, and rigidity) rather than limitations in functional activities/disability,

specifically walking and balance. Since individual areas of the body are scored separately for tremor, bradykinesia and rigidity, this heavily weights their influence on both the motor section and total score (Schenkman et al. 2010). Another criticism of the motor section of the UPDRS is that the items lack uniform anchors, hence a given numeric score on an item does not mean the same thing as the same numeric score on another item (Schenkman et al. 2010). The one item on balance, retropulsion or the “pull test” as it is commonly known, measures reactive balance rather than the proactive anticipatory postural control, which is essential for activities of daily living, self-care, and mobility in static and changing environments (Bloem et al. 2001; Dibble 2006,). The criticism of the one item on gait is that walking is tested in a stationary unchanging environment with the examiner and patient alone in the room navigating over a set course, thus requiring limited prediction. Household ambulation needed for performance of daily activities, and community ambulation needed for participation in work leisure recreational and social activities, both require predictive skills to allow for the adaptation to changing environments (Dibble 2006; Shumway-Cook et al. 2007; Horak et al. 2010).

A new edition of the UPDRS, sponsored by the Movement Disorder Society, and incorporating the recommendations of the Movement Disorder Society task force (Movement Disorder Society 2003), was released in draft form in 2006, its clinimetrics were established in 2007, and the final instrument was published in 2008 (Goetz G et al. 2007; Goetz et al. 2008a; Goetz et al. 2008b). The new version is named the Movement Disorder Society Unified Parkinson’s Disease Rating Scale (MDS-UPDRS). The overall intent of the MDS-UPDRS was three-fold, first to characterize the severity of disease as well as the burden it poses on patients and caregivers, second to define the longitudinal course of PD, and third to be sensitive enough to detect minimal clinical change in therapy trials (pharmacological and rehabilitation) (Goetz G et al. 2008). The internal

consistency of the MDS-UPDRS was measured with Cronbach's alpha, and was 0.79-0.93 across sections (section I-0.79, section II-0.90, section III-0.93, and section IV-0.79). Concurrent validity was assessed by correlating the UPDRS with the MDS-UPDRS, both total scores and section scores (total score $r=0.96$, section I $r=0.79$, section II $r=0.92$, section III $r=0.96$, and section IV $r=0.89$). Internal validity was measured by correlating total scores and section scores of the MDS-UPDRS (sections I&II $r=0.67$, sections I&III $r=0.43$, sections I&IV $r=0.39$, sections II&III $r=0.066$, II&IV $r=0.44$, and sections III&IV $r=0.22$). Based on percentage of lowest or highest scores there were no floor or ceiling effects in sections I-III, however in section IV there was the expected floor effect but no ceiling effect (highest score =36.7% and lowest 0.1%). Factor analysis by comparative fit index and exploratory factor analysis showed that many items loaded on more than 1 factor and some did not load on any factor. Therefore the recommendation is not to sum the section scores to a total score, and second not to combine any section scores in analyses (Goetz G et al. 2008).

The MDS-UPDRS retains the 4 sections of the UPDRS, however these are renamed and items have been added and revised to detect clinically pertinent PD problems not adequately covered in the older version. Additionally there are clinician and patient/caregiver questionnaires, so that when appropriate, the patient and his/her caregiver can answer questions based on typical daily experience rather than a single clinician evaluation. Unlike the UPDRS where anchors focused on severe or marked impairments, the 5 point scoring of the MDS-UPDRS shifts toward the differentiation of slight from moderate disease (Goetz et al. 2004). All items on the MDS-UPDRS are rated on a 0-4 scale which has defined anchors across all items. A score of 0 implies the absence of any problems. The score 1 or "slight" refers to symptoms that are so infrequent and of such low intensity that they have no impact on usual daily routine. A

score of 2 or “mild” refers to symptoms of an intensity and frequency to create a modest impact on function. The score 3 or “moderate” refers to symptoms that are frequent or strong enough to impact function significantly but not prevent function. Finally a score of 4 or “severe” refers to symptoms that are severe and frequent enough to prevent function (Goetz et al. 2008).

Section I of the MDS-UPDRS is now titled “non-motor experiences of daily living”, and its 13 questions aim to quantify the impact of the non-motor symptoms of PD. The clinician questionnaire includes the older version items on cognition, hallucinations, and depressed mood, but adds items on anxiety, apathy and indications of dopamine dysregulation syndrome. The patient/caregiver questionnaire adds sleep problems, daytime sleepiness, urinary dysfunction, and constipation, in addition to pain and abnormal sensations from the older version section II and dizziness or light-headedness on standing from the older version section IV. Section II is now called “motor experiences of daily living”, and is designed to be completed in its entirety by the patient/caregiver. Most of the items are similar conceptually to the original UPDRS, however they have been revised to reflect the experience of the activity rather than the task itself (e.g. feeding rather than using utensils) (Goetz G et al. 2007). Of the 13 item section total, two new items include participation in hobbies and other activities, and getting in and out of bed. Section III, designed to be completed by the clinician, remains titled “motor examination” and consists of 18 items. The main changes are in the evaluation of tremor, which has been divided to postural and kinetic tremor, rest tremor amplitude, and constancy of tremor. An item on toe tapping has been added, and the old item on bradykinesia is changed to global spontaneity of movement. Section IV is titled “motor complications”, and its 6 items refer to dyskinesias and motor complications. Unlike the UPDRS where section IV had a dichotomous yes/no scoring, the MDS-

UPDRS scores each item on the 0-4 point scale with the anchors described above. Rather than simply measuring their presence or absence as on the older scale, the MDS-UPDRS quantifies the time spent with dyskinesias and their impact on the patient's daily function. The MDS-UPDRS further divides motor fluctuations to time spent in the OFF state, functional impact, and complexity, as well as the predictability and suddenness of "OFF" times (Goetz et al. 2008).

The MDS-UPDRS, unlike its predecessor, has directions embedded within the body of the test form that guide clinicians and patients/caregivers on the overall scale, its sections, and its items individually. The intent of the detailed instructions is for clinicians across the world to apply the MDS-UPDRS in a standardized way so that scores can be compared. Since there are clinician and patient/caregiver forms, the MDS-UPDRS is written with vocabulary of a seventh grader, is free of medical jargon, and clearly indicates that the patient should answer the questions when able, but requires documentation when the caregiver answers as proxy for the patient. Additionally there are separate descriptions for the "ON" & "OFF" PD medication states for sections III & IV (Goetz et al. 2008). Originally the appendix was supposed to include a comprehensive guideline of more specific tests for each non-motor symptom, the MDS-UPDRS appendix is now an official list of the recommended (established clinometric data and previous application to PD), and supplemental evaluation tools (those that do not meet all the criteria above). The appendix is electronic to allow for frequent updates, and is intended to guide clinicians to a group of more uniform measures to allow better comparisons in research (Goetz et al. 2008). Unfortunately the MDS-UPDRS was not published at the start of the "Gait and Step Training to Reduce Falls in Parkinson's Disease", the randomized control study from which the data for the current study was gathered.

A study that aimed to validate the MDS-UPDRS part 1 for non-motor experiences of daily living, tested for internal consistency, floor and ceiling effects, concurrent validity and convergent validity. Factor analysis of MDS-UPDRS part 1 showed that there were 2 factors, the first containing items on depression, anxiety and apathy, and the second containing items on sleepiness, fatigue, urinary problems, constipation, pain, light-headedness, cognitive deficits, and hallucinations (Gallagher et al. 2012). Internal consistency for the entire section was high with Cronbach's alpha equal to 0.85. The internal consistency for the depression anxiety apathy factor was 0.69 and for the other non-motor symptoms factor was 0.82. Floor and ceiling tested by percentage highest and lowest scores, was small for floor effects (2%) and 0% for ceiling effects. There was an excellent correlation between the original UPDRS section I and the non-motor experiences of daily living section of the MDS-UPDRS ($r=0.81$, $p<0.001$) indicating concurrent validity (Gallagher et al. 2012). Convergent validity was established comparing individual items on the MDS-UPDRS part I with corresponding established clinical scales for the same domain, including but not limited to the scales for outcomes in Parkinson's disease (SCOPA), Hamilton depression scale (HAD), Hamilton anxiety scale, Lillie apathy rating scales, Epworth sleepiness scale, frontal assessment battery, and Pittsburgh sleep quality index. The correlations between the standardized z-score of the MDS-UPDRS part I and the composite z-scores of the other non-motor symptoms scales was strong ($r=0.89$, $p<0.001$). There were significant correlations ($r>0.61$) for the MDS-UPDRS part I for items on hallucinations, sleep problems, constipation, lightheadedness on standing, fatigue, pain and other sensations, and apathy. The correlations between the MDS-UPDRS part I and items on depression, anxiety, daytime sleepiness, and urinary problems were moderate but still significant ($r=0.40-0.60$). The

correlation between the MDS-UPDRS part I and the cognitive scales was low ($r=0.26-0.33$) and not significant (Gallagher et al. 2012).

The profile of function and impairment level experience with Parkinson's disease (PROFILE PD) was created in an attempt to overcome some of the limitations of the UPDRS, design a single instrument that could be used in early and mid-stage as well as later disease, and finally be comprehensive enough to guide assessment and treatment in the physical therapy clinic (Cutson et al. 1999). Its development paralleled the revision of the UPDRS. The original PROFILE PD underwent pilot testing in the clinic, reliability and validity testing, item analysis, and exploratory factor analysis. As a result of this testing, 4 items were deleted, and 4 items were rewritten, so that the current PROFILE PD has 24 items (Cutson et al. 1999). Factor analysis of the original tool identified 3 sections and they were retained in the final version. Section 1 has 11 items that look at impairments in body systems (tremor, rigidity, postural instability); section 2 has 10 items examining limitations in functional activity (bed mobility, transfers, and walking), and section 3 has 3 items rating problems with memory, depression, and participation in the community. The 0-4 rating scale is anchored so that 0 corresponds with no disease, 1 with slight disease, 2 with mild disease, 3 with moderate disease, and 4 with severe disease. Each item choice is further described to avoid ambiguity, and there are clear directions to the examiner incorporated within the body of the instrument. The total score is the sum of the 3 sections and hence ranges from 0-96 with higher scores indicating more disability. Most measure constructs similar to the UPDRS, however they are reworded for clarification. There are several new items- transfers, fine motor performance, and involvement in daily and social/leisure activities. Items not included from the UPDRS include swallowing and salivation, orthostasis, sleep disorder and problems with nausea, anorexia, or vomiting. Unlike the UPDRS which rates individual

areas of the body separately for agility, tremor, and rigidity, the PROFILE PD uses a single score for the key PD symptoms. Items in section 4 of the UPDRS were scored by yes no answers, however items from UPDRS section IV (not included in the UPDRS final score) are incorporated into the 3 sections of the PROFILE PD and are scored with the 0-4 scale and counted in the total score (Schenkman et al. 2010). Inter-rater reliability was 0.97 by Shrout Fleiss estimation, and internal consistency, measured by Cronbach's alpha, was 0.853. The PROFILE PD correlated highly with the UPDRS ($r=0.86$, $p<.0001$) and negatively but strongly with the SES ($r=-0.83$, $p<.0001$) (Schenkman et al. 2010). Exploratory factor analysis suggested 1 major component along with 2 minor components that correlated, and explained 43.8% of the variance in PROFILE PD scores. Therefore the developers of the PROFILE PD recommend use of the total score not section scores or combinations of section scores (Schenkman et al. 2010).

MEASURING BALANCE IN PARKINSON'S DISEASE – USE OF BALANCE MEASURES DEVELOPED FOR THE ELDERLY POPULATION

To overcome the limitations of the UPDRS in measuring balance in persons with PD, researchers and clinicians tried to apply existing clinical balance tests (Functional Reach Test, Timed up and Go, Berg Balance Scale, Performance Oriented Mobility Scale, Balance Evaluation Systems Test), with established reliability and validity to predict falls in the elderly, to do the same thing in the client with PD (Morris et al. 2001; Behrman et al. 2002; Brusse et al. 2005; Lim et al. 2005; Dibble 2006; Steffin et al. 2008; Schenkman et al. 2010). In fact the cutoff points with the highest sensitivity and specificity to predict falls in the elderly were often arbitrarily generalized to the person with PD, without substantiating whether these cutoff points were indeed valid in PD (Dibble et al. 2006). Similarly alternatives to overcome the limitations of the UPDRS to measure walking emerged (dynamic gait index, functional gait assessment, 10 meter walk

time, timed comfortable and fast walking speed), and again, failed to distinguish whether performance in the well elderly mirrored performance in persons with PD (Brusse et al. 2005; Lim et al. 2005; Steffin et al. 2008; Tanji et al. 2008; Foreman et al. 2010; Horak et al. 2010; Schenkman et al. 2010). These tests for balance and walking are presented below.

The Functional Reach Test (FRT) is a test of stationary balance, where the subject is asked to stand beside a wall grid, raise the inner arm to shoulder level and make a fist. The point where the third metacarpal head meets the grid is noted. The client is asked to lean forward at the hips and reach forward with the raised arm as far as possible without having to touch the wall, lift the heel, or take a step. The point where the 3rd metacarpal head meets the grid in the reach position is measured and the distance between the original and second point is referred to as the “functional reach”. The objective of the FRT is to see how willing a patient is to reach outside stability limits in the forward direction, and it is predictive of risk for falls. After a practice session, the test is usually performed twice and the mean value is calculated as the functional reach (Duncan et al. 1990). Test-retest reliability measured with one day to 1 month intervals between examinations, was established in healthy elderly clients as well as those with a variety of neurological and musculoskeletal diagnoses. Intra class correlations (ICC) ranged from 0.42-0.92 (Steffen et al. 2008). Test-retest reliability was examined in patients with PD in 3 studies, some which differentiated between patients who fall (fallers) and those who do not fall (non-fallers). FRT, measured in 26 subjects in their home in visits 1 week apart, had an ICC of 0.74 (Lim et al. 2005). Fourteen patients with PD performed FRT in the clinic on two consecutive days and their test-retest reliability was 0.84 (Schenkman et al. 1997). The final study looked at 10 elderly subjects with no known neurological impairment and 20 subjects with PD tested 1 week apart, and reported ICC values of 0.62

for the elderly, 0.93 for persons with PD with a history of falling and 0.42 for patients with PD with no history of falls (Smithson et al. 1998). Minimal detectable change, the smallest change in scores to be clinically (and functionally), significant ranged from 4-11 centimeters in studies on well elderly (Steffen et al. 2002). In the study carried out in the patient's home with 26 subjects referred to above, the minimal detectable change was 12 centimeters (Lim et al. 2005). A second study on minimal detectable change in a 1 week period, calculated for fallers and non-fallers, was 8 centimeters and 4 centimeters, respectively (Smithson et al. 1998).

The FRT has established predictive validity in the elderly (Steffen et al. 2002). Behrman tested whether the FRT could differentiate between fallers and non-fallers in individuals with PD (Behrman et al. 2002). She recruited 58 subjects with PD, and further divided them to the faller, (1 or more falls in the past 6 months), and non-faller PD groups. Additionally she recruited 15 subjects to serve as healthy elderly controls. There were 30 subjects who met the criteria of the PD falls group, and 13 who met the criteria for the PD no falls group. Three trials of the FRT were performed and the scores were averaged. Mean scores and standard deviations in centimeters were 36.4 ± 7 for the control subjects, 33.4 ± 9 for the patients with PD with no fall history, and 27.5 ± 8.5 for the PD participants with a fall history. There was a significant difference between the PD falls group and the control group as well as a significant difference between the PD fallers and PD non-fallers ($p < 0.001$) (Behrman et al. 2002). To determine predictive validity of the FRT in PD, the falls group was further divided dichotomously to those with scores of less than 24.5 centimeters and those with scores equal to or more than 24.5 centimeters (10 inches), the previously identified cutoff criterion (Duncan et al. 2002). Sensitivity, in this case, the ability of FRT to accurately identify those at risk for falling when the person scored less than 24.5 was low at 30%. Specificity, the ability of FRT to

correctly identify those at no risk for falling when the person is categorized as a non-faller, was 92%. Positive predictive value is an estimate that those who tested less than the criterion score of 24.5 really are PD fallers, and in this study was 90%. The negative predictive value is an estimate that those who reach further than 24.5 centimeters are classified as non-fallers, and was 36%. Since the sensitivity is so low in persons with PD, using a cutoff of 24.5 centimeters would miss many persons fall and need therapy (Behrman et al. 2002).

The Berg Balance Scale (BBS) was designed to discriminate elderly community dwelling individuals who are at risk for falling from those not at risk for falling (Berg et al. 1992). Unlike other multi-dimensional tests of balance, the BBS does not examine any aspects of gait. The 14 items are hierarchically arranged, and include items thought to represent tasks of everyday life. Items include static maintenance of postures in sitting, standing with a narrow base of support, standing with eyes closed, standing tandem, and standing on one leg (Berg et al. 1992). Items that measure transfer ability include moving from sitting to standing and vice versa as well as transferring between two level surfaces one with armrests and the second without armrests. Dynamic balance is measured by reaching forward, turning to look over each shoulder, and stepping with alternate feet onto a step 10.16 centimeters (4 inches) high (Berg et al. 1992). The 14 items on the BBS are scored on a Likert scale of 0-4, for a maximum score of 56. Higher scores on the BBS correspond with better static and dynamic balance and hence less risk for falls. Scores below 44 indicate high risk for falls, while scores of 44-47 indicate moderate falls risk. Persons with scores between 47 and 51 typically use a cane when walking, especially walking in the community (Shumway-Cook et al. 1997). The internal consistency of the BBS was evaluated in a group of community dwelling elder persons. Cronbach's alpha for both total and individual items is high, ranging from 0.85-0.98 (Berg et al. 1995).

Test-retest reliability in the elderly, measured by intra class coefficient (ICC) one week apart is high ($r=0.87$) (Berg et al. 1995; Steffin et al. 2008). The Minimal detectable change (MDC) values in tests performed 1 week apart on average, ranged from 4-7 in studies of healthy adults living in the community (Berg et al. 1995), was 2 for 26 persons with PD (Lim 2005), was 5 for 24 elderly persons some with stroke (Liston et al. 1996; Mao et al. 2002), was 4 for 5 people with traumatic brain injury (Newstead et al. 2005). The BBS was correlated with the UPDRS motor section, the modified H&Y scale and the SES in 38 male subjects with PD in order to test its criterion validity (Qutubuddin et al. 2005). There was a significant and negative correlation between the BBS and UPDRS motor section ($r=-0.58$, $p<0.005$), a significant negative correlation between the BBS and modified H&Y Scale ($r=-0.45$, $p<0.005$), and a significant positive correlation between the BBS and the SES ($r=0.55$, $p<0.005$) (Qutubuddin et al. 2005). The high test-retest reliability, moderate to high internal consistency, and significant correlations with measures of disease severity and activities of daily living, make the BBS a useful measure of balance in the elderly, and persons with diverse neurological conditions including PD (Qutubuddin et al. 2005; Steffen et al. 2008).

The Timed up and Go (TUG) was designed to measure how well a sample of elderly community dwelling adults, both healthy and with a variety of medical conditions (arthritis, stroke, Parkinson's disease, cerebellar disorders and deconditioning) would perform on a sequence of activities typical of daily living, namely standing up from a standard height arm chair, walking 3 meters, turning around, walking back to the chair and sitting down. The subject is timed from when the tester says "go" indicating to the client to stand up, until the subject is safely seated back in the chair (Podsiadlo et al. 1991). Test-retest reliability in this community dwelling sample of elderly persons was excellent ($ICC=0.89$) (Podsiadlo et al. 1991). Test-retest reliability, as measured by

Pearson correlations coefficients in a healthy elderly population ranged from 0.81-0.99 (Steffen et al. 2002). Test-retest reliability for a sample of 26 patients with PD, tested in the home setting, and ON PD medications was high (ICC=0.85) (Lim et al. 2005). Morris (2001) evaluated test-retest reliability in a sample of 12 patients with PD and 12 age and height matched controls, who performed 5 repetitions of the TUG both OFF (a minimum of 12 hours since the last evening dose of PD medications) and ON PD medications (1 hour after the first morning dose of PD medications) for the subjects with PD (Morris S et al. 2001). The control group performed 5 trials at a convenient time. All sessions were videotaped so that 3 experienced therapists and 2 clinicians inexperienced in the TUG could rate the tapes at their convenience. Test-retest reliability, measured by Pearson product correlations, ranged from 0.80-0.98 OFF PD medications, 0.73-0.99 ON medications and was 0.90-0.97 for the control group, across the 5 trials of the TUG. Furthermore, there was a significant difference in PD patient and control subject performance across the 5 trials. In the OFF medication state for subjects with PD, trials 1 and 5 were significantly different than trials 2-4. There was no significant difference in performance across the 5 trials of the TUG for PD subjects ON medications; however, in the control group trial 1 was significantly different from the rest. It was recommended to give patients a practice trial before timing the TUG, and to limit repetitions to less than 4, to prevent a learning effect and increased speed. Removing trials 1 and 5, and averaging the remaining trials 2-4 improved test-re-test reliability (Morris S. et al. 2001). Inter-rater reliability was good to excellent for 3 inexperienced raters (ICC=0.87 OFF medications, 0.99 ON medications) and was excellent for 3 experienced raters ($r=0.99$ ON & OFF PD medications) (Morris S. et al. 2001). Additionally there was a statistically significant difference in TUG performance across trials 2-4 between patients with PD ON & OFF PD medications ($t=3.78$, $p=0.003$), and between subjects with PD ON medications and

healthy controls ($t=3.79$, $p=0.002$) (Morris S. et al. 2001). A study of 9 men with PD, (H&Y stages 3 and 4), tested over 7 days, had test-retest reliability of 0.75 (ICC), MDC of 5 seconds (Smithson et al. 1998). Twenty six individuals with PD were evaluated in their home to measure intra-rater reliability and smallest detectable difference. Intra-rater reliability, as measured by intra class coefficient (ICC), was 0.88; the smallest detectable difference was calculated to be 5 seconds (Lim et al. 2005).

The Performance Oriented Mobility Assessment (POMA) (formerly the Tinetti Mobility Test) is a reliable and valid test originally designed to measure balance and gait in elderly persons living in assisted living, nursing homes, or long term care facilities (Tinetti 1986). There is sufficient reliability and validity data from testing in the elderly to support use of the two scales (balance and gait) both individually and in combination. The balance subscale consists of 9 items (sitting balance, coming to standing and immediate standing balance thereafter, standing balance, standing overcoming a backward perturbation, standing eyes closed, standing with a narrow base of support, turning 360 degrees, and sitting down). These items are scored on a 0-2 scale with higher scores corresponding with better performance. Items in the gait section (initiation of gait, step length and height, step symmetry, step continuity, path deviation, trunk stability, and walking stance or heel width) are scored on the same scale. Maximum score for the balance section is 16, and for the gait section 12, resulting in a total score of 28 points (Tinetti 1986). A strength of the POMA is that it includes items on tasks that are known to cause falls in the elderly and in persons with PD, specifically coming to standing from sitting, sitting down slowly from a standing position, initiating gait when standing, and turning when walking (Tinetti 1996; Kegelmeyer et al. 2007; Steffin et al. 2008). Inter-rater reliability of the POMA for a sample of 30 patients with PD, measured with ICC scores, was 0.87 with a 95% confidence interval of 0.80-0.93 (Kegelmeyer et al. 2007).

Intra-rater reliability for 30 patients with PD (mean age 65 ± 10.9 , mean H&Y stage $2.41 \pm .39$, mean disease duration 9.4 ± 7.3 , and 77% male) was determined by having 2 experienced physical therapists and 4 student physical therapists rate a videotape of a patient performing the POMA with one week in between viewings. The ICC scores ranged from 0.69 (0.44-0.83) to 0.88 (0.77-0.94); there was no significant difference between the student and physical therapists' scores ($p < 0.01$) (Kegelmeyer et al. 2007). Concurrent validity of the POMA in patients with PD was established comparing scores on the POMA with scores on the motor section of the UPDRS and with comfortable walking speed. There was a negative correlation between the total POMA and the UPDRS motor score ($r = -0.45$, $p < 0.05$), between the balance section of the POMA and the UPDRS motor score ($r = -0.40$, $p < 0.05$), and between the gait section of the POMA and the UPDRS motor score ($r = -0.43$, $p < 0.05$). The correlations between the POMA total score, POMA balance score, and POMA gait score and comfortable walking speed were 0.53, 0.52, and 0.50 respectively ($p < 0.01$) (Kegelmeyer et al. 2007). There have been studies that evaluated the predictive validity of the POMA in comparison with other balance/falls risk measures in persons with PD (Smithson et al. 1998; Lin et al. 2005). Lin showed that the POMA had stronger predictive validity than a series of scales including FRT, TUG and single leg stance. Smithson found that the gait section of the POMA was more predictive than the combination of the retropulsion test, the Romberg, tandem stance, and single limb stance in detecting recurrent fallers, persons having > 1 fall in a 6-12 month period (Smithson et al. 1998; Bloem et al. 2001). A retrospective review of 126 charts from a movement dysfunction clinic, which included scores for the UPDRS motor section, POMA, and comfortable walking speed, along with performance scores for the same tests for 30 patients in the lab, were used to establish criterion validity for subjects with PD. In the chart reviews, where 65% of the patients were male, the

mean and standard deviation for age was 68.8 ± 11.04 , and the mean and range for H&Y stage was 2.5 (1-5) (Kegelman et al. 2007). The sample was further divided into 4 groups- group 1 (n=25) those who fell in the past week and scored less than 20 on the POMA (the cutoff point for falls risk in the elderly); group 2 (n=39) those who had not fallen in the past week and scored less than 20 on the POMA; group 3 (n=9) those who fell in the past week and scored greater than 20 on the POMA; and group 4 (n=77) those who had not fallen in the past week and scored greater than 20 on the POMA. It should be noted that 116/156 subjects had not fallen within the week prior to performance testing or chart review. When the cutoff of 20 was selected with the intent being to maximize both sensitivity and specificity, the sensitivity (likelihood of having scored less than 20 and having fallen in the past week) was 76% (range 57%-88%), the specificity (likelihood of scoring >20 and having not fallen in the past week) was 66% (range 57% - 75%), the positive predictive value (estimated probability of being at falls risk when POMA scores were <20) was 34% (range 24%-45%), negative predictive value (estimated probability of not being at falls risk when POMA scores were >20) was 91% (range 82% - 96%), positive likelihood value (the increased probability of being a faller if one scores <20 on the POMA) was 2.25 (range 1.64-3.1) and finally negative likelihood value (the decreased probability of being a faller if the POMA score is >20) was 0.37 (range 0.2-0.67) (Kegelmeyer et al. 2007). A cutoff score of 23 is suggested in persons with PD if the intent is to maximize sensitivity and minimize negative likelihood values, thus optimize chances of not missing a person at risk for falls (Kegelmeyer et al. 2007).

The Balance Evaluation Systems Test (BESTest) is based on a translation of Bernstein's systems model of motor control, to a systems model of balance (Shumway-Cook et al. 1997). The balance model suggests that there are 6 inter-related systems, (biomechanical constraints, stability limits and verticality, anticipatory postural

adjustments, postural responses, sensory orientation and stability in gait), that need to be functioning independently, but also in an integrated manner with alternating dominance between them (Shumway-Cook et al. 2007). The 27 items of the BESTest are each designated to one of the 6 balance system categories. The thought behind BESTest was to help physical therapists differentiate types of balance deficits and thus link examination and evaluation findings to treatment interventions. Sixteen of the 27 items of the BESTest are derived from existing balance and falls evaluations for the elderly, including the FRT, BBS, TUG, dynamic gait index (DGI) and Clinical Test of Sensory Organization and Balance (CTSIB). Breaking the items down by category, the items under biomedical constraints category include- base of support, center of body mass alignment, ankle strength and range of motion, hip/lateral trunk strength, and finally sit on floor and stand up. The items under the stability limits/verticality category include- sitting verticality left and right then lean to the left and right, and functional reach lateral to the left and right. The anticipatory postural adjustment category include- the items sit to stand, rise to toes, stand on one leg left and right, alternate stair touching, and standing arm raise. The items that make up the postural response category include in-place response forward, in-place response backward, and compensatory stepping correction forward, backward, and laterally, with the left and/or right foot. Sensory orientation is measured by two items - the first the modified CTSIB (stand on firm and compliant surfaces with eyes open and closed) and second the score for standing on an incline with eyes closed. Finally the stability and gait category items include - gait on level and unlevel surfaces, gait with changes of speed, gait with vertical and/or horizontal head turns, gait with pivot turns, gait with steps over obstacles, and finally scores on the TUG and TUG with a simultaneous cognitive task. Each item is scored on a 4 point ordinal scale, where higher

points correspond with better performance. There are explicit directions for tester and client, and a training DVD is available for purchase (Horak et al. 2009).

Psychometric evaluation of the BESTest was carried out at 2 different sessions, (one for all sections except biomechanical constraints, and a second for the sections on biomechanical constraints and gait stability) each on a convenience sample of 12 subjects, 3 healthy control subjects, 3 persons with PD, 5 subjects with single or bilateral vestibular dysfunction and 1 with a combination of peripheral neuropathy and total hip replacement. One of the 12 subjects had a history of falls in the past 6 months to a year, that being a person with bilateral vestibular dysfunction. Inter-rater reliability at each session was carried out with 9 raters (physical therapists with neurological experience, physical therapists with orthopedic experience, physical therapy and movement science faculty and researchers) who viewed the tests simultaneously while the participant performed the test. They had previous training on scoring the test (Horak et al. 2009). Inter-rater reliability for the test as a whole was ICC=0.91 (95% CI 0.83-0.97). Inter-rater reliability for the 6 categories ranged from ICCs of 0.79-0.96, with stability limits and verticality scoring the lowest and sensory orientation scoring the highest. Kendall Coefficient of Concordance for Ordinal Measures was used to determine the degree to which raters agreed on section scores and item scores. Kendall coefficients ranged from 0.79-0.95 for individual balance systems and from 0.46-1 for the individual items. The item standing and raising arms overhead was scored 3 for all 12 subjects by all raters. Timed items also showed higher agreement rates between raters. Items with the lowest concordance were alignment, ankle strength and range of motion, and lateral lean to the left and right (Horak et al. 2009). Variability in performance on the BESTest was highest in the patients with PD. Healthy control subjects scored highest on the BESTest and patients with PD scored the lowest. The section that was particularly challenging for the

subjects with PD was postural stability. Concurrent validity of the BESTest was established comparing its scores with those of the ABC. The BESTest total scores correlated significantly with each subject's average ABC test score ($r=0.685$, $p<0.05$). The ABC scores demonstrated modest correlation with the individual sections of the BESTest ($r=0.41-0.78$). The BESTest correlated strongly with the BBS (ICC=0.98), and POMA (ICC=0.75-1.0). The subsections of the BESTest also correlated highly with established tests like FRT (ICC =0.79 total test and ICC=0.98 with section 2 limits of stability and verticality), CTSIB (ICC=0.74 total test and ICC=0.96 compared with section 5 sensory orientation), and TUG (ICC=0.98 total test, and ICC =0.88 for section 6 gait stability) (Horak et al. 2009).

The discriminative validity, inter-rater reliability and test-retest reliability of the BESTest was determined in 80 persons with PD, where 25 were identified as having had >2 falls in the past 6 months. There were significant differences between the faller and the non-faller groups in duration of disease (fallers 11.4 ± 5.5 and non-fallers 7.15 ± 3.81 years), median H&Y scale (fallers = 3 and non-fallers = 2), and the mean score on the MDS-UPDRS total score (fallers = 93.8 ± 23.1 and non-fallers 62.9 ± 19) (Leddy et al. 2011a). Inter-rater reliability was high (ICC=0.96, 95% confidence interval 0.89-0.99), and test-retest reliability ranged from 0.88-0.91 in student physical therapists and physical therapists. The cutoff point that maximized sensitivity and specificity was $\leq 69\%$. Using that cutoff point, sensitivity was 0.84, specificity was 0.76, positive likelihood ratio was 3.49 (95% CI 2.11-5.77), negative likelihood ratio was 0.21 (95% CI 0.09-0.52), posttest probability with BESTest score $<69\%$ was 61.3%, and posttest probability with BESTest scores $>69\%$ was 8.7% (Leddy et al. 2011a). The cutoff point that maximized sensitivity and negative likelihood ratio was $\geq 84\%$. Using that cutoff, sensitivity was 1, specificity was 0.39, positive likelihood ratio was 1.64 (95% CI 1.32-

2.02), negative likelihood ratio was 0, posttest probability with BESTest scores <0.84 was 42.7% and posttest probability with BESTest scores >0.84 was 0% (Leddy et al. 2011a).

In an effort to decrease the 30-35 minute average administration time of the BESTest, a shortened version, the Mini BESTest, was created by eliminating section I biomechanical constraints of movement and section II stability limits. The Mini BESTest requires 10-15 minutes to complete, and is thus clinically feasible. The 16 items of the mini Bestest are scored on a 0-2 scale (unlike the BESTest that utilizes a 0-3 scale) and maximum score on the mini BESTest is 32 (compared with 108 on the BESTest) (Leddy et al. 2011b). The mini BESTest, BESTest and sections of the BESTest were examined in 80 patients with PD where 25 subjects had fallen 2 or more times in the past 6 months. This sample was the same as that described for the BESTest above, and differed significantly in disease duration, H&Y scale stage, and MDS-UPDRS total score. There was a strong significant relationship between the BESTest and mini BESTest ($r=0.955$) (Leddy et al. 2011b). Inter-rater reliability for the Mini BESTest (ICC) was 0.91 (range 0.75-0.97) as compared with the BESTest, which was 0.96 (range 0.89-0.99), and the sections of the BESTest, which was 0.89 (range 0.79-0.96) (Leddy et al. 2011b). Test-retest reliability for the Mini BESTest (ICC) was 0.92 (range 0.82-0.96) as compared with the BESTest, which was 0.88 (range 0.72-0.95), and the sections of the BESTest, which was 0.69 (range 0.63-0.87) (Leddy et al. 2011b). The test-retest reliabilities for section I (biomechanical constraints of movement), section II (limits of stability and verticality), and section V (sensory organization) were not statistically significant (Leddy et al. 2011b). The cutoff score for the Mini BESTest that maximized both sensitivity and specificity was \leq to 20/32 or 63%. Using this cutoff, sensitivity was 0.88, specificity was 0.78, positive likelihood ratio was 4.03 (95% CI 2.40-6.79) negative likelihood ratio was

0.15 (95% CI 0.05-0.45), posttest probability with a score less than 63% was 64.7%, and posttest probability with score \geq 63% was 6.5%. The cutoff score for the Mini BESTest that optimized both sensitivity and negative likelihood ratio, was \leq 23/32 or 72%. Using that score sensitivity was 0.96, specificity was 0.47, positive likelihood ratio was 1.82 (95% CI 1.40-2.37), negative likelihood ratio was 0.08 (95% CI 0.01-0.59), posttest probability with a score \leq 72% was 45.3% and posttest probability with a score greater than 72% was 3.7% (Leddy et al. 2011b). Accuracy of the scores as measured by AUC was 0.86 (95% CI 0.76-0.95) for the mini BESTest and was 0.84 (95% CI 0.75-0.93) for the BESTest (Leddy et al. 2011b).

SELF-PERCEIVED MEASURES OF BALANCE

The 16 item Activities Specific Balance Confidence Scale (ABC) is a scale designed to measure the elderly person's perception of confidence performing a variety of daily living tasks (Powell et al. 1995). Each item is scored from 0-100% with 0 indicating no confidence in performing the task without losing one's balance, to 100% indicating full confidence in completing the task safely. The total score is the average of the scores on the 16 items. There is a hierarchy of difficulty of the tasks with the easiest being reaching at eye level, walking around the house, getting in and out of the car, walking outside to a nearby car and walking across the parking lot. Tasks of intermediate challenge include sweeping the floor, going up and down steps, picking up a slipper from the floor, walking in a crowded mall, and walking up and down an incline. The most difficult 6 items include walking in a crowd being bumped, riding an escalator holding onto the rail, reaching on tiptoes, standing on a chair to reach, riding an escalator without holding on and walking on an icy sidewalk (Powell et al. 1995). Test-retest reliability of the ABC in a sample of 60 community dwelling seniors age 65-95, and tested 2 weeks

apart was high ($r=0.92$, $p<0.001$) (Powell et al. 1995). Cronbach's alpha, measuring internal consistency of the ABC, was 0.96, and was statistically significant for all items with the exception of walking around the home and walking across a parking lot (Powell et al. 1995). Fifty seven percent of the participants in this study reported a fall within the past year, and 38% of these falls resulted in injury. Fear of falling (FoF) was reported in 57% of the subjects and 30% limited activities due to fear of falling. Those who had fallen had ABC total scores that were lower than those who did not fall, but the difference was not statistically significant ($p=0.058$). Similarly the ABC total score of those who had fallen and sustained an injury was not significantly different than those who had fallen but were not injured (Powell et al. 1995). Using clients' self-classification of mobility levels, those with low mobility levels had significantly lower total scores on the ABC ($p<0.001$), were significantly older ($p<0.001$), had more comorbidities ($p<0.01$), and required more assistance with daily activities ($p<0.001$), when compared with the high mobility group (Powell et al. 1995).

A shortened ABC scale was developed in Israel by identifying the 25th percentile of items that had the highest area under the curve (AUC) on receiver operated characteristic (ROC) curves on the original ABC 16 item scale (Peretz et al. 2006). The items on this scale were reach on tiptoes, reach while standing on a chair, walk in a crowd and be bumped, ride the escalator holding the rail, ride the escalator not holding the rail, and walk on an icy surface. These six items are known as the ABC₆. The internal consistency and discriminant validity of the ABC and the ABC₆ were examined in 70 persons with high level gait disorders (HLGD), 19 persons with PD, and 68 control subjects. When looking at the 16 item ABC scale, Cronbach's alpha for the HLGD control and PD groups was 0.90, 0.83, and 0.91 respectively. For the ABC₆ Cronbach's alpha for the same groups was 0.81, 0.86 and 0.90 respectively. Logistic regression

models were applied to determine sensitivity and specificity of the long and shortened ABC scales for each of the groups. Sensitivity in the group with HLGD compared with the control group on the 16 item ABC scale was 96% and on the ABC₆ was 91%. Sensitivity when comparing the subjects in the PD and control groups was 58% on the long version and 53% on the shortened version. Finally, the sensitivity when comparing the HLGD and PD groups on the 16 item ABC and the ABC₆ were 97% and 99% respectively (Peretz et al. 2006). Specificity on the ABC and abbreviated ABC₆ were 96% and 93% for the HLGD and control groups, 96% and 96% for the PD and control groups and 32% and 32% for the HLGD and PD groups (Peretz et al. 2006). The intra class coefficient was used to calculate the relationship between the ABC with 16 items and the ABC₆, and was 0.88 for the control group, 0.83 in the PD group, and 0.78 in the HLGD group (Peretz et al. 2006). Unfortunately, despite its satisfactory psychometric properties, the ABC₆ was not available at the start of the current study.

A second shortened ABC scale, developed by a Dutch physical therapist, included 6 items, of which 5 were the same as those of Peretz (Oude Nijhuis et al. 2007). The items were selected not only by using the 25th percentile for AUC from ROC curves, but also by calculating the mean difference of these items in the PD and control groups. The 5 similar items were reach while standing on tiptoes, reach while standing on a chair, walk in a crowded mall and be bumped, ride the escalator not holding rail and walk on icy sidewalks. The item that was omitted in the Dutch version was ride the escalator holding the rail, and the item that replaced it was walk in a crowded mall since it was thought to relate to freezing of gait (Oude Nijhuis et al. 2007). The 16 item ABC and ABC₆ (Peretz) scales were translated into Dutch and tested for internal consistency, and area under the ROC curves in a sample of 50 patients with PD, and 60 age matched controls. Cronbach's alpha for internal consistency was 0.97 for the long scale and 0.93

for the ABC₆ (Peretz). AUC for the ABC 16 item was 0.79, and was 0.77 for the ABC₆ (Oude Nijhuis) (Oude Nijhuis et al. 2007). An even shorter 5 item version of the ABC scale was developed by calculating the 5 items with the highest AUC of ROC curves in a sample of 89 patients with PD, 64% male, mean H&Y stage 2.3±0.05, and mean disease duration 8.2±5.2 years (Lohnes et al. 2010). The 5 items selected were the same as those on the ABC₆ (Peretz), with the exception of riding the elevator holding onto the rail, which was thought to be redundant (Lohnes et al. 2010). Each of the 3 shortened versions were compared with the 16 item ABC scale using intra class coefficients, and their internal consistency was calculated using Cronbach's alpha. The relationships between all the shortened versions and the 16 item ABC scale were all greater than 0.91 (ABC₆ Peretz and ABC₆ Oude Nijhuis = 0.93 & ABC₅= 0.91), and the internal consistency was greater than 0.93 (ABC₆ Peretz & ABC₅=0.93 and ABC₆ Oude Nijhuis =0.94) (Lohnes et al. 2010). The minimal detectable change on the ABC has been determined in elderly subjects residing in nursing homes and in the community, and ranged from 18-38% (Steffen et al. 2008). A single study of 37 persons with PD found that test-retest reliability, measured 1 week apart using intra class correlations, ranged from 0.95-0.96, and minimal detectable change was 13% (Steffen et al. 2008)

MEASURING BALANCE USING WALKING TASKS

In addition to the static and dynamic tests and self-perceived tests of balance described above, there have also been several scales containing a variety of walking tasks that have been utilized to identify elderly persons at risk for falls (Leddy et al. 2011a; Wisely et al. 2004; Shumway-Cook et al. 2007). The dynamic gait index (DGI) is an 8 item measure, scored on a scale of 0-3, where higher scores represent better performance. The intent of the DGI was to be a test of walking skills that could identify persons at risk

for falling in the elderly (Wrisely et al. 2004), in individuals with vestibular (Whitney 2003), in clients with amputations and lower extremity musculoskeletal problems (Shumway-Cook et al. 2007), as well as in persons with a variety of neurological conditions (Shumway-Cook et al. 2007). The DGI has specific patient directions and operational definitions for each of the item choices, however it does not provide instructions for therapists to administer the test or decision rules for scoring (for example when a patient falls in between choices or fits the criteria for more than one choice) (Wrisely et al. 2004). The DGI examines the client's ability to walk while changing speed, turning the head, pivoting, and while negotiating obstacles; additionally it examines the person's ability to ascend and/or descend stairs. Reliability of the DGI was established with 5 physical therapists, trained by the test developer, simultaneously evaluating 5 community dwelling elderly with varying balance skills (Shumway-Cook et al. 2007). Test-retest reliability, measured in sessions 1 week apart, and scored as a ratio of subject to total variability, was 0.96 (Shumway-Cook et al. 2007). Inter-rater reliability measured the same way was 0.98 (Shumway-Cook et al. 2007). A group of elderly persons living in the community was used to identify the score on the DGI that best discriminated between fallers and non-fallers. The cutoff score that maximized sensitivity and minimized false negatives for fall prediction was 19; individuals with scores ≤ 19 were at risk for falling. Using this cutoff score, the DGI was able to discriminate between fallers and non-fallers not only in the elderly, but also in persons with vestibular dysfunction (Wrisely 2004). Concurrent validity of the DGI was established by using Spearman's correlations to compare scores on the DGI and BBS; this score was 0.71 ($p < 0.05$) in a group of 70 persons with vestibular dysfunction. In a group study of young people with various vestibular pathologies, the most common score on the DGI was 21/24 indicating no falls risk, however their dizziness handicap score (a measure of

impact of dizziness on daily activities) indicated moderate disability, suggesting a potential ceiling effect (Whitney et al. 2000).

Wrisley developed the Functional Gait Assessment in response to the potential ceiling effects of the DGI in persons with vestibular dysfunction, the perceived ambiguity of the item choices, and the lack of decision rules for scoring the DGI (Wrisley et al. 2004). The FGA uses 7 items from the DGI eliminating item 7 walking around objects. To overcome the potential ceiling effect, the FGA adds the items walk with a narrow base of support, walk with eyes closed and walk backward, tasks known to be difficult for persons with vestibular dysfunction (Wrisley et al. 2004). Standing and walking with eyes closed is known to increase lateral trunk sway and head instability in older adults as well as those with vestibular disorders (Cromwell et al. 2001). These 10 items are scored on a scale of 0-3 with higher scores indicating better performance (maximum score = 30). The FGA's clinometric properties were established on a sample of 6 female patients, mean and standard deviation for age 58.7 ± 12.4 years by 10 physical therapists, 6 with previous experience utilizing the DGI. Therapists sat on either side of the walkway. The FGA was administered twice with an interval of 1 hour between. The intra-rater reliability, measured by intra class coefficient (ICC) was high (0.88). Test-retest reliability, measured by kappa agreement was 0.50 for the total score and ranged from a low of 0.16 for the item walking with eyes closed to a high of 0.83 for the item walking at a natural speed. Additional items with low kappa values for intra-rater reliability included walking with horizontal and vertical head turns, walking and pivoting 180 degrees, walking with a narrow base of support (Wrisley et al. 2004). Inter-rater reliability, measured in the same way, was 0.50 for the total test, and kappa scores for individual items ranged from 0.34-0.78, or moderate agreement. The two items with low kappa agreements were walking and speeding up and walking and making a pivot turn.

Mean test-retest value for the 10 raters, measured by ICC, was 0.84 (range 0.60-0.99) (Wrisley et al. 2004). Internal consistency measured by Cronbach's alpha was 0.79 for the total FGA score and ranged between 0.12-0.80 for individual items. The correlations for individual items and the total FGA score were weak (range 0.12 - 0.31) for the items walking with a narrow base of support, walk with eyes closed, and manage steps (Wrisley et al. 2004). Principle component factor analysis, applying 3 previously extracted factors, explained 66%-69% of the variability in total FGA scores. Items that loaded on factor 1 were walk at natural pace, walk and change speed, walk with horizontal and vertical head turns, walk and pivot turn, and walk and step over an obstacle. Items that loaded on factor 2 were walk with eyes closed, walk backward and manage stairs. The single item that loaded strongly on factor 3 was walk with a narrow base of support. The item walk backward loaded positively (0.61) on factor one and loaded negatively on factor 2 (-0.60) (Wrisley et al. 2004). Concurrent validity, established in patients with vestibular dysfunction, was measured by correlating the FGA with the ABC ($r=0.64$), TUG ($r=-0.50$), DGI ($r=0.80$) and number of falls ($r=0.66$) (Wrisley et al. 2004).

The inter-rater and test-retest reliability, as well as the concurrent and discriminant validity of the FGA were measured in a sample of 80 patients with PD, 25 who were classified as fallers, having experienced 2 or more falls in the previous 6 month period. Samples of PD fallers and non-fallers were significantly different in disease duration, MDS-UPDRS total scores, and H&Y stages, with fallers having more severe disease and longer disease duration (Leddy et al. 2011a). Inter-rater reliability using 3 raters (2 physical therapists and 1 physical therapy student) was excellent (ICC=0.93, 95% CI 0.84-0.99). Test-retest reliability for the PD patients was high (ICC= 0.80 for the student therapist, and ICC=0.91 for the physical therapists) (Leddy et al. 2011a). Concurrent validity of the FGA in patients with PD was established correlating the FGA

with the modified H&Y scale ($r=-0.669$), MDS-UPDRS ($r=-0.692$), ABC scale ($r=0.707$), BBS ($r=0.783$), and BESTest ($r=0.882$) (Leddy 2011a). The score on the FGA that optimized both sensitivity and specificity was $\leq 15/30$. Using that score, sensitivity was 72%, specificity was 78%, positive likelihood ratio and 95% CI was 3.24 (1.86-5.65), and negative likelihood ratio and 95% CI was 0.36 (0.19-0.39) (Leddy et al. 2011a). Posttest probability with scores ≤ 15 was 59.6% and posttest probability with scores greater than 15 was 14.1%. The score that optimized sensitivity and negative likelihood ratio (to avoid missing fallers) was $\leq 27/30$. Using that score sensitivity was 100%, specificity was 19%, positive likelihood ratio and 95% CI was 1.23 (1.08-1.39), negative likelihood ratio was 0, posttest probability with cutoff score of 27 or less was 35.8% and posttest probability with scores greater than 27 was 0%. The area under the ROC curve indicating accuracy of the FGA was 0.80 (range 0.69-0.90), more accurate than the BBS but not quite as accurate as the BESTest (Leddy et al. 2011a).

SELF-PERCEIVED MEASURES OF WALKING

Just like the ABC scale measures balance self-confidence in the elderly and those with neurological or musculoskeletal dysfunction, there is a recently modified and psychometrically tested self-efficacy scale for walking, the Modified Gait Efficacy Scale (mGES) (Newell et al. 2012). The purpose of the mGES is to measure a person's confidence walking over a variety of ground surfaces, both level and unlevel. The 10 items on the mGES include walking on level surfaces like hardwood floors, walking on grass, navigating an obstacle in one's path, ascending and descending a curb, climbing up and down stairs both holding onto and not holding onto a rail, and walking a half mile. Items are scored on a Likert scale of 1-10 where 1 means no confidence and 10 means full confidence to complete the task safely. Thus scores can range from 10-100 points

(Newell et al. 2012). Psychometric properties of the mGES were established in a sample of 102 community-dwelling elderly persons (mean and standard deviation for age 78.6 ± 6.1) who were able to walk independently with or without a walking aid. The internal consistency of the mGES measured by Cronbach's alpha was 0.94. The standard error of the measure for the mGES was 5.23, that representing the measurement error of the test. Concurrent validity of the mGES, measured by Spearman's rank correlations, was established by comparing scores on the mGES with the ABC ($r=-0.88$, 95% CI 83-92, $p<0.0001$), survey of activities and fear of falling in the elderly ($r=0.59$ activity, $r=-0.71$ fear of falling, $r=-0.54$ activity restriction), late life function and disability instrument ($r=.88$ overall, $r=.32$ disability frequency, $r=0.63$ disability limitation), gait velocity ($r=.064$, 95% CI 0.49-0.75, $p<0.0001$), 6 minute walk test (0.60, 95% CI 0.44-0.72, $p<0.0001$), obstacle walk test ($r=0.61$, 95% CI 0.48-0.73), simple walk test or walking while reciting the alphabet ($r=-0.53$, 95% CI -0.67- -0.36, $p<0.0001$) and complex walking test or walking while saying every second letter of the alphabet ($r=-0.38$, 95% CI, -0.74- -0.48, $p<0.0001$). It should be noted that the mGES did not correlate significantly with either the TUG or narrow walk test. Test-retest reliability was measured in a sub-sample of 26 subjects, representative of the larger sample. Test-retest reliability measured with an average interval of 1 month apart was high (ICC=0.93, 95% CI, 0.85-0.97). There have been no psychometric tests of this measure exclusively in persons with PD. Research on the effectiveness of a balance intervention in patients with PD showed weak correlations between the mGES and performance measures (Liu-Ambrose et al. 2004). The need to measure both walking skills and confidence in walking was emphasized (Newell et al. 2012).

WALKING PARAMETERS AND BALANCE/FALLS RISK

Walking is a complex task that requires motor and cognitive skills for forward progression, while simultaneously attending to the often changing task demands and surrounding environmental conditions (Rochester et al. 2008; Lord et al. 2011a). Walking is essential to the performance of self-care, homemaking, household maintenance as well as vocational, recreational, and leisure skills. Decline in walking ability is associated with decreased quality of life, falls risk, dependence in basic and instrumental activities of daily living, transition to frailty, and disability (Fried et al. 2000; Guralnick et al. 2000; Shumway-Cook et al. 2007; Brach et al. 2011; Newell et al. 2012). Walking has been evaluated observationally (Huang et al. 2008) and using high technology methodologies like motion analysis, instrumented walkways, body worn sensors, foot switches, accelerometers and gyroscopes (Brach et al. 2010; Lord et al. 2011a;). Walking as a single task and walking while simultaneously performing a second task (dual task paradigm) have been studied to tease out the cognitive and attentional demands of gait (Yogev-Seligmann et al. 2008; Yogev-Seligmann et al. 2010; Lord et al. 2011a). Those with executive dysfunction or reduced attention have more difficulty with dual task performance (Lord et al. 2011a).

Researchers have examined both spatial (stride length, step length) and temporal (velocity, cadence, stance and swing time, single and double limb support time) parameters of gait in older adults (Lord et al. 2011a; Brach et al. 2010). Stride length (measured in centimeters or meters) is defined as the distance between where the heel of one leg contacts the ground to where that same heel successively touches the ground on the subsequent step. Step length (measured in centimeters or meters) is the distance from when the heel of one leg touches the ground until the heel of the opposite foot contacts the ground. Cadence is the number of steps taken in a one minute period. Single limb

support time (SLST) is the time when only one leg is on the ground and is between when the toe of one leg leaves the ground, until the heel of that same leg contacts the ground in a successive step. Double limb support time (DLST) is the time when both feet are on the ground, when one leg is making contact with the ground on the current step and the opposite leg toe is leaving the ground from the previous step. Stance time is the time from heel contact of one leg until toe off of the same leg. Swing time is the time between when the toe of one leg leaves the ground until the heel strikes the ground on the successive step. Stance time and swing time can be measured as a percentage of the gait cycle. Stance time of one leg is equal to the swing time of the opposite leg (Huang et al. 2008; Brach et al. 2010).

Gait velocity or walking speed is the distance walked per unit time, and is typically measured in centimeters or meters per second. Stride length and cadence are the gait parameters that modulate velocity. Gait velocity has been used as a marker of the transition to frailty in the elderly and in persons with a variety of medical conditions (Guralnick et al. 2000; Brach et al. 2010, Newell et al. 2012). Since gait is instrumental to the performance of activities of daily living, loss of ambulatory ability increases caregiver burden and decreases quality of life (Sallinen et al. 2011). Additionally, gait velocity has been associated with risk for falling in the elderly and in patients with a variety of medical conditions (Fried et al. 2000; Steffen et al. 2002; Peretz et al. 2006; Hauer et al. 2010; Callisaya et al. 2010; Newell et al. 2012). Gait velocity, when eliminating endurance measures of walking, has been measured over a variety of distances ranging from 3 to 10 meters (Steffen et al, 2008; Lord et al. 2011a). Gait velocity has been measured over ground (Lim et al. 2005; Sallinen 2011) as well as under laboratory conditions with computerized walkways (Hausdorff et al. 2005; Peretz et al. 2006; Callisaya et al. 2010; Newell et al. 2012). While it is more common to measure gait

velocity at the client's comfortable speed, researchers are now looking at fast walking and backward walking as early indicators of functional decline (Steffen et al. 2008; Hackney et al. 2009; Bryant et al. 2011). More recently, gait variability has been utilized as a mechanism to understand normal and pathological gait (Lord et al. 2011a; Lord et al. 2011b). Variability in double limb support time (DLST) is thought to reflect the postural control or dynamic aspect of gait (Lord et al. 2011b). Conversely, stride to stride variability is thought to represent the neural aspect of gait, or the central control of the unconscious rhythmical patterns of gait. Stride to stride variability has been exploited in dual task gait paradigms. Executive and attention strategies are thought to contribute to the neural aspect of gait. Neural control of gait is sensitive to both aging and cognitive decline (Sallinen et al. 2011; Lord et al. 2011a; Lord et al. 2011b).

Since gait is being used to predict falls, examine cognitive status and investigate the neural mechanisms for decline in walking with aging and pathology, it is essential to determine whether the protocols for measuring aspects of gait are replicable, and the measures reliable and valid (Huang et al. 2008; Lord et al. 2011a). A structured review of 10 articles that included 1036 community dwelling elderly with mean age in the 70's, indicated multiple different testing protocols with inadequate information for duplication. Eight studies utilized the GAITRite instrumented walkway (Cir, Havertown, PA), however, it was not always possible to determine the walkway length and specifications, region of the walkway from which data was collected, and acceleration or deceleration distance (Lord et al. 2011a). The DynaPort (MiniMod) was used in two studies, gyroscope with data logging system in 1 study and tri-axial accelerometer in 3 studies. There was inconsistency in measures used to determine gait and variability data, with three spatial measures (step length, stride length and step width) and 6 temporal measures (step time, stance time, swing time, single limb support time and gait cycle time)

identified (Lord et al. 2011a). Gait variability was determined primarily by coefficient of variability, and less frequently by standard deviation. The most frequent reliability measure was test-retest (within session up to two weeks in between), and the most commonly used measured was intra class coefficients, that ranged from a low of 0.11 for stride velocity and a high of 0.88 for stride length. Step length intra-rater reliability varied from study to study, and ranged from low to moderate in 2 studies to high in an equal number of studies (Lord et al. 2011a). Concurrent validity was established comparing gait at slow, preferred, and fast paces to self-rated measures of health, ADL, balance, physical activity and walking (Brach et al. 2008; Lord et al. 2011a). Construct validity was established showing the lack of correlation between gait velocity and step time or step length variability (Moe-Nilsen et al. 2010; Lord et al. 2011a). Responsiveness, measured using both distribution and anchor rated methods, and described as an effect size or standard error measure, was poor over all but best (moderate) for stance and swing time variability (Lord et al. 2011a). Recommendations for future studies using gait variability as an outcome measure include: 1.) justification of gait parameter selected by factor being tested – rhythmicity (stride to stride variability) versus dynamic postural stability (step width or DLST variability); 2.) selection of walking distance based on the parameter being measured (20 meters or 25 steps for step time and step length variability and hundreds of strides for gait velocity variability; 3.) utilization of continuous walks versus interrupted walks where spatiotemporal gait parameters may not have had sufficient time to stabilize; 4.) avoidance of pooled data for the left and right legs since it may obscure asymmetry; 5.) utilization of coefficient of variability which is dimensionless and allows comparison, opposed to standard deviation which varies for different variability measures (high CV and SD likely for parameters of postural control, and low CV and SD more representative of rhythmicity and progression); 6.) selection of step length variability

over step width variability as the optimal measure for postural stability; 7.) measurement of test-retest reliability with a longer interval between testing sessions optimally 1-2 weeks; 8.) differentiation between walking as a single task and dual task walking until reliability is established individually and then comparatively; 9.) specification of whether variability is calculated using individual or group means and standard deviations; and finally 10.) consideration of the detectable change that is clinically meaningful (Brach et al. 2010; Lord et al. 2011a).

Test-retest reliability for comfortable walking speed in elderly persons living in the community has been reported to range from 0.79-0.95 as measured by intra class correlation coefficients (Steffen et al. 2008; Lord et al. 2011a). In samples of elderly persons with known diagnoses of osteoarthritis of the knee, hip fracture, knee arthroplasty and osteoporosis, test-retest reliability ranged from 0.88-0.97 measured by intra class correlations (Steffen et al. 2008). Minimal detectable change for walking at usual speeds without an assistive device, as determined in 4 cohorts of healthy persons over 60 followed in longitudinal studies over a 10 year period, was found to range from 0.06-0.14 meters/second (Lusardi et al. 2003; Steffen et al. 2008). Studies that followed subjects between 1 and 5 years found higher minimal detectable change ranges, specifically 0.25-0.29 meters/second. It was difficult to determine the number of persons walking with an assistive device, since use of a cane in the community was not an exclusion criterion (Steffen et al. 2008; Lord et al. 2011a). Minimal detectable change for comfortable walking speed in persons with osteoporosis was 0.25 meters/second, and in hip fracture was 0.49 meters/second (Kennedy et al. 2006; Steffen et al. 2008).

Gait velocity in samples thought to be representative of the elderly population has been the subject of many researchers (Huang et al. 2008; Brach et al. 2011). In a sample of 241 elderly adults, mean age 80.3, who walked at a normal speed on a 12 foot

GAITRite (Cir, Havertown, PA), mean and standard deviation for gait velocity was 96.1 ± 21 centimeters per second (centimeters/second) at baseline, and was 93.8 ± 22 centimeters/second one year later. Subjects were asked to rate their walking difficulty (worse, same, better) and walking distance (less, same, more) at the end of the one year follow-up. Those who reported no walking difficulty both at baseline and 1 year later, walked at a mean and standard deviation for gait velocity of 101.9 ± 9 centimeters/ second at baseline, and 101.2 ± 19.2 centimeters/ second 1 year later. Those who reported no difficulty walking at baseline but developed difficulty over the year, walked at a mean and standard deviation for gait velocity of 92.1 ± 21.3 centimeters/second at baseline, and 86.4 ± 21.4 centimeters/second 1 year later. The estimated meaningful decline in gait velocity was 5.0 centimeters/second. Those who had difficulty walking at baseline but no difficulty walking 1 year later, had a mean and standard deviation for gait velocity of 94.8 ± 19.6 centimeters/second, and 95.6 ± 19.9 centimeters/second respectively. Finally, those who had difficulty walking both at baseline and one year later, had a mean and standard deviation for gait velocity of 83.1 ± 25.5 centimeters/second, and 77.6 ± 22.4 centimeters/second respectively. Meaningful improvement was estimated to be 6.2 centimeters/second. Those who reported no change in their walking distance over a 1 year period, had a mean and standard deviation for gait velocity of 99.6 ± 20.9 centimeters/second at baseline, and 98.7 ± 23.2 centimeters/second 1 year later. Those who reported walking less over the 1 year period, had mean and standard deviation for gait velocity of 92.0 ± 23 centimeters/second, and 86.1 ± 20.5 centimeters/second at follow up. Meaningful decline was estimated to be 4.97 centimeters/second. Those who reported that gait distance increased from baseline to follow up 1 year later, walked with a mean and standard deviation for gait velocity of 90.1 ± 17.2 centimeters/second initially, and

89.6±19.2 centimeters/second later The estimate of meaningful improvement was 0.43 centimeters/second (Brach et al. 2011).

Presence or absence of stance time variability was evaluated by observational and instrumented walkway gait analysis in 46 elderly subjects, mean age 81.2 years old. Those who showed stance time variability at baseline walked at a mean and standard deviation for gait velocity of 104.23 centimeters/second; this difference was statistically significant ($p < 0.001$) (Huang et al. 2008). In an attempt to determine whether more difficult walking tasks (walking in a narrow space, walking stepping over an obstacle in the path, walking and reciting the alphabet, and walking and reciting the alphabet every other letter) would better identify those at risk for falling, 71 elderly persons were recruited, and their walking speed was followed over a 1 year period. They were separated into 3 groups based on a decline ($n=18$), no change ($n=43$), and improvement of gait velocity ($n=10$) between baseline and follow-up one year later. The group whose performance declined, had initial mean and standard deviation for gait velocity of 131 ± 17 centimeters/second, and a follow up gait velocity of 112 ± 18 centimeters/second. Those whose performance improved, had initial and follow up mean and standard deviation for gait velocity of 118.10 centimeters/second, and 138.8 centimeters/second respectively. There was no significant difference in gait velocity between the groups; however, gait velocities were significantly different at baseline and one year later. The cost of walking under more difficult conditions was defined as gait velocity at baseline minus gait velocity performing the more challenging task. For walking in a narrow space, the mean and standard deviation for cost of walking was 43 ± 16 centimeters/second for the group that declined, 33 ± 17 centimeters/second for the group that remained unchanged, and 22 ± 18 centimeters/second for the group that improved; the 3 groups were significantly different ($p=0.009$). Mean and standard deviation for cost of walking stepping over an

obstacle was 35 ± 15 centimeters/second for the declining group, 26 ± 12 centimeters/second for the stable group, and 13 centimeters/second in the improving group; the groups were significantly different ($p=0.003$). The mean and standard deviation for cost of walking reciting the alphabet was not significantly different in the 3 three groups, and was 14 ± 15 centimeters/second, 11 ± 10 centimeters/second, and 15.8 centimeters/second, for the declining, stable, and improving groups respectively. The mean and standard deviation for cost of walking reciting every other letter in the alphabet simultaneously was not significantly different between the 3 groups, and was 31 ± 18 centimeters/second, 28 ± 17 centimeters/second and 24 ± 18 centimeters/second for the declining, stable, and improving groups. The odds ratio and 95% confidence interval for narrow walking was 1.46 (1.02-2.11), and for obstacle walking was 1.82 (1.16-2.86) (Brach et al. 2011).

Gait has been examined extensively in patients with PD (Morris et al. 2001; Lord et al. 2009; Bryant et al. 2011; Lord et al. 2011; Rochester et al. 2011). The person with PD, especially OFF medications, walks with hallmark features of a forward stooped posture, excessive flexion at the hips and knees, reduced trunk rotation with rigid coupling of the upper and lower trunk, reduced speed, decreased stride length, reduced excursion of hip knee and ankle joints, reduced ground clearance, reduced ground reaction forces, and decreased or absent arm swing (Morris et al. 2001). The posture and force regulation deficits in PD result in a slow shuffling gait, where reduced foot clearance increases the risk for falls (Morris et al. 2001). Step size and the scaling of steps are thought to be regulated by the basal ganglia supplemental motor area and premotor cortex circuit, which is responsive to dopamine. While gait velocity improves with dopamine medications, it remains at two thirds that of age-matched elderly controls, for example 1.23-1.5 meters per second for elderly and 0.67-1.0 meters/second in the

subjects with PD (Morris et al. 2001; Steffen et al. 2008; Morris et al. 2009). Stride length, even at optimal medications levels, is still two thirds of that of age matched control subjects. Stride length is sensitive to the level of dopamine medications in the person with PD, and ranges from 1.2-1.5 meters for healthy elderly, to 0.8 – 1.0 meters at end dose dopamine, and 0.4-0.9 meters when dopamine is totally withdrawn. Dopamine medications have no effect on temporal variables of gait for example, cadence, and duration of both stance and swing. It is thought that the rhythmicity of gait is a function of the cerebellum, brainstem, and spinal centers, all being modulated by frontal motor cortices. Cadence is similar in persons with PD and age-matched elderly, and is between 100-110 steps per minute. Double limb support time, (a measure of postural stability), is increased in patients with PD from the 20-30% of the gait cycle in elderly adults, to as much as 35% of the gait cycle (Morris et al. 2001; Morris et al. 2010; Bryant et al. 2011).

Even though dopaminergic medications improve gait velocity and stride length, the ON-medications state is not free from problems. Foot sensor measurements show that during the gait cycle, the person with PD puts less pressure on the heel at loading, less pressure on the forefoot and toes at push-off or unloading, and more pressure on the midfoot as compared with control subjects (Morris et al. 2001; Morris et al. 2010). The patient with PD has inadequate dorsiflexion at the beginning of the gait cycle, and contact with the ground is often made with a flat foot rather than the heel. Nevertheless the strength and firing of the tibialis anterior muscle is within normal. (Morris et al. 2001). The flexed posture of the person with PD does not allow translation of the center of body mass forward over the stance foot, and may contribute to the lack of roll over and push off typical of this disease. The decreased pressure on the forefoot at unloading coincides with decreased strength in the plantarflexor gastrocnemius muscle (Morris et al. 2001). Two consequences of this type of gait are increased risk for tripping and falling, and

increased energy expenditure (Morris et al. 2001). Motor fluctuations occur with dopamine therapy and gait variability is sensitive to them (Morris et al. 2001; Bryant et al. 2011; Lord et al. 2011b). When the person with PD is optimally medicated, there is minimal stride to stride variability. As medications wear off or are withdrawn, marked variability in gait emerges, and performance from trial to trial varies considerably. This variability is likely not caused by the pathophysiology of PD, but rather by the medications used to treat it (Morris et al. 2001; Bryant et al. 2011; Lord et al. 2011b). The person with PD can utilize visual cues in the form of horizontal lines across the walking path to increase stride length, and it is thought that the visual cues result in activation of the frontal cortex to compensate for the deficient basal ganglia (Morris et al. 2001; Rochester et al. 2011). Thus, the person with PD can generate normal walking patterns, but there is a deficiency in the amplitude of this system (Morris et al. 2001; Bryant et al. 2011; Rochester et al. 2011).

COMFORTABLE WALKING SPEED

Comfortable walking speed has been measured extensively in persons with PD, and is an indicator of overall walking performance (Steffen et al. 2008; Lord et al. 2009; Yogev-Seligmann et al. 2012). Walking speed was measured as patients with PD walked on instrumented walkways, over ground in the laboratory, and in their home (Lim et al. 2005; Bryant et al. 2011; Lord et al. 2011b). Test-retest reliability was established in a group of 26 individuals with PD, who walked at their usual walking speed for 10 meters in their homes, on average, one week apart. Intra class coefficients were 0.81 for walking speed and 0.88 for step count (Lim et al. 2005). Minimal detectable change (MDC) for gait velocity in this sample was calculated to be 0.19 meters/second for comfortable walking speed, or slightly less than the mean 0.25 meters/second change in elderly

populations (Lim et al. 2005; Steffen et al. 2008). There have been no studies that looked at test-retest reliability and MDC for fast walking (Steffen et al, 2008).

Studies comparing the ON & OFF PD medication state in persons with PD have helped differentiate dopaminergic and non-dopaminergic pathways for control of gait. Dopamine pathways appear to be more closely related to the spatial aspects of gait than the temporal ones (Rochester et al. 2008; Lord et al. 2009; Lord et al. 2011b; Yogeve-Seligmann et al. 2012). A sample of 33 persons with PD (mean and standard deviation for age 70.61 ± 9.23 years, mean and standard deviation for H&Y stage 2.58 ± 0.42 , mean and standard deviation for disease duration 9.65 ± 5.8 years), walked at a mean and standard deviation for gait velocity of 0.83 ± 0.26 meters/second OFF medications and at a speed of 0.98 ± 0.19 meters/second ON medications (Bryant et al. 2011). Similarly in a group of 40 people with PD, (mean and standard deviation for age of 69.2 ± 6.2 years, predominantly in H&Y stages 2.5-3, mean and standard deviation for disease duration 8.7 ± 5.1 years), mean and standard deviation for gait velocity was 0.69 ± 0.19 meters/second OFF medications and 0.78 ± 0.18 meters/second ON medications (Lord et al. 2011b; Rochester et al. 2011). Finally 29 persons with PD, (mean and standard deviation for age 69.7 ± 7.4 years, predominantly H&Y stage 2 and 3, mean and standard deviation for disease duration of 5.8 ± 5.5 years) walked at a speed of 0.85 ± 0.22 meters/second OFF medications (Lord et al. 2010).

Since PD not only affects motor but also cognitive functions, specifically attention and executive function, dual task studies have been used to tease out which parameters of gait require attention and which do not (Lord et al. 2011b; Yogeve-Seligmann et al. 2012). Fifty patients with PD were recruited to examine the effect that performing a second motor task while walking had on gait velocity. Mean and standard deviation for age of the participants was 69.2 ± 6.6 years, mean and standard deviation

for disease duration was 8.7 ± 5.5 years, and most subjects had moderate disease severity as measured by H&Y stage. The first task was to walk from a table in the living room to the kitchen (an average of 6.5 meters away). For task 2 they picked up a tray with 2 plastic cups filled with water from the counter in the kitchen, walked back to living room carrying the tray, placed the tray on the table where they started, and sat down in an adjacent chair. These two tasks were performed first after dopamine medications had been withdrawn for 12 hours with testing first thing in the morning, and then 1 hour after taking PD medications. Mean and standard deviation for single task walking speed was 0.7 ± 0.23 meters/second and dual task walking speed was 0.60 ± 0.21 meters/second OFF medications. ON medications single task walking speed was 0.78 ± 0.18 meters/second, and dual task walking speed was 0.70 ± 0.22 meters/second. Older females, with greater disease severity and fear of falling, walked more slowly for single task walking. For the dual walking task, those OFF medications, with greater disease severity, greater depression, and fear of falling walked more slowly. In both tasks fear of falling accounted for 10% of the variability in gait velocity (Lord 2011b). Twenty nine subjects with PD were recruited to determine the effect disease severity, executive function, and different aspects of attention had on walking speed when OFF medications. Mean and standard deviation for age of the subjects was 71.3 ± 10 years, and mean and standard deviation for disease duration was 5.8 ± 5.5 years. Five subjects were H&Y stage 1, 11 were H&Y stage 2, and 13 were H&Y stage 3. Tasks 1 and 2 were identical to the tasks described above. These two tasks were repeated but subjects wore headphones, and had to count number of tones played during walking. Task 3 was thus walking while counting tones, a dual motor and cognitive task. Task 4 was a multi-task with walking, carrying a tray, and counting tones performed simultaneously. Mean and standard deviation for gait velocity for the single walking task was 0.85 ± 0.23 meters/second, and

decreased to 0.64 ± 0.20 meters/second for the dual motor task- walking and carrying a tray. Walking speed decreased less for the dual motor and cognitive task, and was 0.76 ± 0.29 meters/second. Walking speed for the multi-task deteriorated significantly to 0.58 ± 0.18 meters/second. Participants also completed the UPDRS motor section, the Hayley & Brixton test of cognition, and The Everyday Attention (TEA) scale sections for attention (phone search), divided attention (phone search with tone counting), and sustained attention (lottery task) (Robertson 1994; Burgess 1997; Lord 2010). Disease severity as measured by the motor section of the UPDRS, as well as sustained attention (and auditory memory) as measured by the (TEA) lottery task accounted for 47% of the variability in scores for task 1, and 58% of the variability of gait velocity scores in task 2. The sole predictor of gait velocity in tasks 3 and 4 was UPDRS motor score for disease severity, accounting for 50% and 65% of the variance respectively. Interference scores were calculated for the dual motor, dual motor and cognitive, and multi-task situations. Higher negative scores indicated more interference. The interference scores were -23.5 ± 15.4 , -13.6 ± 17.2 and -31.6 ± 14.8 respectively. Executive function, as measured by the Hayley & Brixton, and disease severity, as measured by the UPDRS motor section, accounted for 12% of the variability in the dual motor task interference score. UPDRS motor score, sustained attention, auditory memory as measured by the TEA lottery, and divided attention as measured by the TEA phone plus distraction, accounted for 66% of the interference score for motor and cognitive dual task, and 58% of the interference score for the multi-task. The authors concluded that as disease severity progresses in PD, patients have more difficulty performing dual tasks simultaneously, and are more prone to falling when doing this (Lord et al. 2010).

Gait has been measured in patients with PD to determine the effect various types of cues, both external visual or auditory cues, or internal attention-based cues, have on

spatial and temporal parameters of gait (Rochester et al. 2011). Fifty persons with PD, mean and standard deviation for age of 69.2 ± 6.2 years, mean and standard deviation for disease duration of 8.69 ± 5.19 years, predominantly of moderate disease severity (12 H&Y stage 2.5, 32 H&Y stage 3) were recruited. Forty of the participants experienced freezing of gait. Falls history by self-report for the 6 months prior to the study was 0 for 23 participants, 1 for 7 participants, and more than 1 or repeated falls for 10 participants. Mean and standard deviation for UPDRS motor scores ON & OFF PD medications were 34.98 ± 9.31 and 22.92 ± 9.16 respectively. Single limb stance OFF medications was 6 and 5 seconds for the left and right legs, and was 8 & 7 seconds ON medications. Similar to previous studies, dopamine medications significantly improved gait velocity, stride length and stride time, and scores on the UPDRS motor section decreased (improved). Dopamine had no significant effect on single limb stance time, the measure for balance (Morris et al. 2001; Lord et al. 2011b). A repeated measures analysis of variance showed a main effect for type of cues on gait velocity, stride length and stride time ($p < 0.001$). There was no main effect for medications and there were no interaction effects. Post hoc tests showed that both internal cues (focused attention on length of step) and external cues (focused on taking long steps to the metronome beat) equally improved stride length as compared to no cues, however external cues were superior. Step frequency was decreased by both types of cues compared to the non-cue situation; however internal cues produced a greater reduction in step frequency. In summary, external cues as well as dopaminergic medications improve gait velocity primarily by increasing stride length (Rochester et al. 2011).

FAST WALKING SPEED/MAXIMAL WALKING SPEED

A population based study of 412 community dwelling elderly, (mean and standard deviation for age 71.6 ± 7.1 years for females and 72.4 ± 7 years for males, who were able to walk a minimum of 3 meters with or without an assistive device), examined the effect of age on variability of spatial and temporal variables of gait in men and women (Calisaya et al. 2010). Gait data was collected on the 4.6 meter GAITRite (Cir, Havertown PA) from 6 walks for each subject, producing a mean and standard deviation of 27.3 ± 5.4 steps for analysis. There were no differences between left and right leg variability measures; therefore results were averaged for the two sides. Men walked faster than women, and had greater variability in step length and step width, both spatial aspects of gait (Calisaya et al. 2010). There was a significant relationship between age and greater variability in spatial measures of gait, for example stride length and width, in both males and females. Similarly there was a significant relationship between age and greater variability of temporal measures of gait, specifically step time and DLST in both genders (Calisaya et al. 2010). Faster speed was associated with less variability of all measures with the exception of step width. All relationships were linear with the exception of age with step length variability in women, which was curvilinear (Calisaya et al. 2010). Multiple linear regression was used to model the relationship between age and gait variability. After adjusting for height, weight, speed, and chronic disease, the association between age and gait variability measures was confirmed in both genders. Controlling for presence of self-reported chronic disease did not alter the association between age and gait variability, except for arthritis where there was increased variability in step time. Adjusting for gait speed reduced the magnitude of the association between age and temporal variables by 62-86%, between age and step length variability 25%, and between

age and step width variability 5-12% (Calisaya et al. 2010). Thus, speed of walking must be considered especially if variability of temporal measures is being examined.

Six hundred and five community dwelling elderly were recruited to examine relationships between maximal walking speed (MWS), balance, and lower extremity power (Sallinen et al. 2011). Mean and standard deviation for age was 77.5 ± 1.9 years old, and mean and standard deviation for body mass index (BMI) was 28 ± 4 kilograms per meter squared. Data was also collected on drinking and smoking status, as well as presence or absence of depressive symptoms, cardiovascular or cardiopulmonary disease, and musculoskeletal comorbidities. Since gender was not shown to be significant in preliminary analysis, data for male and female participants was pooled (Sallinen et al. 2011). MWS was measured as participants were timed walking 10 meters over ground with a 2-3 meter acceleration area at the start. Lower extremity power was measured by dynamometer. Balance was measured by tandem stance time. Physical activity level was measured as the number of hours reported exercising in the previous week (Sallinen et al. 2011). Mean and standard deviation for MWS was 1.4 ± 0.4 meters/second (range 0.3-2.9 meters/second). Mean and standard deviation for lower extremity power was 104 ± 5.3 watts (range 81-123 watts). Tandem stance times ranged from a low of 26 ± 8.2 seconds and peaked at 29.6 ± 3.2 seconds (Sallinen et al. 2011). Subjects were divided into quartiles based on MWS, and ranges for balance and lower extremity power were determined for each quartile. Participants were divided into three groups based on exercise level in the previous week. The “inactive group” did not participate in any exercise in the previous week; the “insufficiently active group” exercised up to three hours per week maximum; the “active group” exercised greater than 4 hours per week. There were several significant relationships between walking speed, lower extremity power, balance, and physical activity level. First, lower extremity power increased

significantly as MWS increased. Second, there was a significant difference in balance times between the groups, when classified for level of exercise in the previous week. Third, subjects who were more physically active walked significantly faster. Fourth there was a significant difference between the groups in chance of being a drinker, having musculoskeletal disease, and having depressive symptoms. These characteristics were highest in the slowest MWS quartile and were lowest in the the fastest MWS quartile. Presence of cardiovascular disease did not vary between the groups (Sallinen et al. 2011). Stepwise multiple regression analysis was used to determine the degree to which the demographic, physical function and activity, life-style, and comorbidity status factors contributed to maximal walking speed (MWS). Age, female gender, and BMI (model 1) accounted for 11.4% of the variability of MWS. Adjusting for lower extremity power, standing balance, and physical activity level (model 2) explained 38.3% of the variability of MWS. The adjustment for smoking and drinking status (model 3) added 6.6% to the model. Finally adjusting for presence of musculoskeletal and pulmonary disease as well as depressive symptoms (model 4) explained 47.4% of the difference in MWS. The single factors that contributed most to the difference in walking speed, based on the standardized regression coefficient, was lower extremity extensor power (Sallinen et al. 2011).

The effect of gait velocity and dopamine medication state on variability of gait was examined in 33 patients (22 males) with PD. Mean and standard deviation for age was 70.61 ± 9.3 years old, mean and standard deviation for H&Y scale was stage 2.58 ± 3.42 , and finally, mean and standard deviation for disease duration was 9.65 ± 5.8 years. OFF medications, mean and standard deviation for gait velocity for comfortable walking speed was 82.7 ± 26.59 centimeters/second, and for fast walking speed was 123.91 ± 35.62 centimeters/second. ON medications, mean comfortable walking speed was 98.94

± 19.2 centimeters/second, and mean fast walking speed was 135.76 ± 27.59 centimeters/second (Bryant et al. 2011). Dopamine significantly reduced variability in stride length, stride velocity, step time, and double limb support time. Increased gait velocity resulted in significant reduction of variability of stride length and stride velocity. Temporal variability measures were not significantly altered by speed (Bryant et al. 2011).

BACKWARD WALKING

Backward walking has been examined in elderly populations (Laufer 2005). It has been documented that elderly walk significantly more slowly backward than forward. The reduction in gait velocity was produced primarily by decreased stride length, with minimal to no change in cadence (Hackney et al. 2009). Swing time, as a percentage of the gait cycle, was lower backward than forward, and double limb stance time increased from forward to backward walking. Variability in gait between trials was higher for backward than forward walking, particularly in stance as a percentage of the gait cycle (Hackney et al. 2009). A study compared 78 persons with PD with 75 control subjects on several parameters of the walking cycle on the GAITRite (Cir, Havertown PA), walking three trials each forward and backward. There was no significant difference in age between the groups and it averaged 65.10 years old. There were a few more females in the group with PD (28% female PD to 23% female control). The mean and standard deviation for time since onset of PD was 8.2 ± 5 years. H&Y stage ranged from 1-3, with 2 at H&Y stage 1, 49 at H&Y stage 2, and 8 each at H&Y stages 2.5 and 3. Fifty percent of the participants with PD had experienced a fall within the previous 6 month period. A two way analysis of variance was used to examine whether direction of walking, or group assignment, affected forward and backward walking. There was no significant difference

in gait velocity between the PD group and the control group and it averaged 1.2 meters/second. Both the PD and control groups walked more slowly backward than forward. The PD group walked significantly more slowly than the control group backward (0.7 vs. 0.9 meters/second) (Hackney et al. 2009). Stride length decreased significantly for both groups from forward to backward walking. The PD group had shorter mean and standard deviation for stride length than the controls both in forward (1.3 ± 0.04 to 1.4 ± 0.01 meters), and backward walking (0.7 ± 0.01 to 1.0 ± 0.01 meters) direction. Swing time, as a percentage of the gait cycle, decreased from forward to backward walking for both groups; however, the PD participants in both walking conditions had lower swing times. Double limb support time (DLST), as a percentage of the gait cycle, increased significantly from forward to backward walking for both groups. There was a significant difference in DLST between the groups in backward walking, with the PD group spending significantly more time in double limb support. Similarly stance, as a percentage of the gait cycle, increased significantly from forward to backward for both groups; however, again the PD group had greater stance time than the controls in both forward and backward walking. Cadence was relatively stable across walking conditions for both groups, although the PD group had higher cadence overall (Hackney et al. 2009). Participants with PD also performed the Berg Balance Scale and the motor section of the UPDRS, and scores on these measures were compared with walking speed forward and backward. As scores increased on the motor section of the UPDRS, backward gait velocity decreased significantly ($r=-0.29$, $p=0.01$), but there was no significant correlation between UPDRS motor score and forward velocity. As UPDRS motor scores increased, the risk for falls also increased. As BBS scores increased, both forward ($r=0.486$, $p<0.001$) and backward ($r=0.538$, $p<0.001$), walking speeds increased. As forward walking speeds increased so did backward walking speeds ($r=0.766$,

$p < 0.001$) (Hackney 2009). Backward walking was much more challenging than forward walking for both persons with PD and older adults, and thus needs to be examined as part of routine screening. Since scores are so different between forward and backward walking, there may be different central and peripheral control mechanisms.

TURNING

Turning is an essential element of many daily living routines like getting washed in the bathroom in the morning, or making a meal in the kitchen. It is estimated that turning occurs 5 times for every 10 meters walked in the household situation (Huxham et al. 2008a). Turning has been identified as a task which is difficult for persons with PD (Morris et al. 2001; Stack et al. 2006; Huxham et al. 2008a; Huxham et al. 2008b). The majority of studies examined turning to various targets between 30 and 120 degrees when walking; turning 30-120 degrees encompasses 78% of turns in everyday life (Morris et al. 2001; Stack et al. 2006; Huxham et al. 2008b). A few studies examined 180 degree turns, but these are not frequently used when functioning in the home (Huxham et al. 2008a). Studies identify several differences between young persons, elderly control subjects, and persons with PD (Morris et al. 2001; Huxham et al. 2008a). There was a single study that looked at test-retest reliability of turning 180 degrees in 12 newly diagnosed persons with PD, not taking dopamine medications, and 14 age-matched controls. Patients walked with gyroscopes attached to the sternum and leg shanks, and data from the sensors was sent to a data logger attached to the waist. Mathematical modeling was applied to the data (Salarian et al. 2011). Intra class correlations and 95% confidence intervals were established for peak angular velocity, turning time, number of steps before the turn and number of double steps in turning. The ICC for peak angular velocity was good (ICC=0.86, 95% CI 0.67-.095). The ICC for duration of turn was excellent (ICC=0.89,

95% CI 0.74-0.96). The ICC for steps prior to the turn was good (ICC=0.85, 95% CI 0.64-0.94). However the test-retest reliability for double steps in the turn was poor (ICC=0.22, 95% CI 0.27-0.62) (Salarian et al. 2011). This study of newly diagnosed patients examined the postural stability gait dysfunction index (PIGD), the summed scores of items 27-30 of the UPDRS motor section. The average score for these patients was 0.67 (range 0-3) on a 0-16 point scale, with higher scores meaning more disability. The PIGD index was not sensitive to small differences in turning ability in the denovo patients (Salarian et al. 2011). Patients with PD had significantly longer turn durations, and delays in their last step before turning. While PIGD index was not sufficiently sensitive to detect change in mild PD, turning duration was sufficiently sensitive, and did increase over an 18 months, in these denouvo patients (Salarian et al. 2011).

A study examined turning in 10 persons with PD, and 10 controls, matched for age, height, and weight. The groups differed on mini mental status test scores (maximum score 30, with higher scores indicating better mental status) with the PD group having slightly lower scores, mean and standard deviation 27.7 ± 1.8 , compared with 29.3 ± 1 for the controls. Ninety percent of the participants with PD were in H&Y stages 2 or 2.5. Mean and standard deviation for disease duration was 7.4 ± 5.1 years, and for motor score on the UPDRS was 14.2 ± 5.6 (Huxham et al. 2008a,b). Turns were performed while motion analysis sampled a total of 5 steps, 2 into the turn, and 3 out of the turn. Walking without turning, persons with PD walked 68% slower than controls, had stride lengths 74% that of controls, had step times 108% that of controls, and spent 34% more time in double limb support than controls (Huxham et al. 2008a). The PD group failed to turn as far to the target as the control group for 60 degree turns (PD 85%, controls 95%), and for 120 degree turns (PD 64%, controls 87%). Persons with PD required significantly more steps for each turn, with the number of steps increasing directly with the magnitude

of the turn (Morris et al. 2001; Huxham et al. 2008a). Therefore persons with PD took more steps to turn a smaller distance (Morris et al. 2001; Huxham et al. 2008a). Both groups increased stride width approaching the turn; however, control subjects turned more acutely resulting in a cross-over stride after the turn, which was absent in 57% of the PD trials. Persons with PD had more difficulty with the abrupt arrest of forward movement, and sudden change of direction required for an acute turn. All movements after the turn were under scaled in persons with PD (Stack E, et al. 2006; Huxham et al. 2008). The PD group reduced stride length during turning significantly more than the control subjects, and more so for larger magnitude turns. After the turn, persons with PD retained their shortened stride compared with the controls, who increased stride length immediately (Huxham et al. 2008a). Larger turns (120 degrees) were more challenging than smaller turns (60 degrees). The percentage of double limb support time was as high as 62% in the PD group, compared with 23% in the control group for 120 degree turns (Huxham et al. 2008a). Persons with PD showed less rotation during turning than their age-matched controls, with the limitation of motion being greatest between the shoulder and pelvis. Control subjects, on the other hand, dissociated upper and lower trunk, and showed reciprocal rotation (Morris et al. 2001; Huxham et al. 2008a; Huxham et al. 2008b). Despite stride length differences, footstep patterns during turns were similar between groups, but scaled down in PD. Similar to walking, persons with PD were able to generate the appropriate spatial temporal adjustments for turning, but were unable to maintain the correct amplitude during their execution (Huxham et al. 2008a).

PARKINSON'S DISEASE SPECIFIC BALANCE & GAIT MEASURES

The Gait and Balance Scale (GABS) is one of the few clinical measures designed exclusively for patients with PD. It was developed to overcome some of the limitations of

the UPDRS in measuring gait and balance, specifically the single item for balance (retropulsion) and the single qualitative item for gait (Thomas et al. 2004). The first 7 items of the GABS are historical questions about independence in self-care, perceived difficulty walking, presence of freezing and modifying factors, and finally presence of falls and limitation of activity due to fear of falling (Thomas et al. 2004). These items are taken directly from the UPDRS. There are 14 performance items that are derived from the UPDRS, BBS, POMA, FRT, and TUG; hence they have been previously tested in both the elderly and persons with PD. Two items are modified from assessments of disability in PD by Webster (Webster 1968). There are 3 timed tests that are not part of the score - walking at usual speed, walking at fast speed, and a modified TUG, with the walking distance of 5 meters. Balance items include- stance with feet together eyes open and eyes closed, tandem stance, single limb stance, functional reach, foam posturography and postural stability (retropulsion). Gait assessment includes- heel toe and tandem walking, arm swing, as well as items from the modified POMA gait section, specifically initiation of gait, step height and length, step width, step continuity, path deviation, and trunk movement during walking (Thomas et al. 2004). The historical and balance items are scored on a 0-4 scale with higher scores indicating poorer performance. Walking items are scored 0-2. POMA items are scored dichotomously 0 or 1. Intra-rater reliability, measured using kappa agreement OFF medications on two consecutive days, ranged from 0.41-0.84. Items with kappa ≥ 0.80 (excellent- very good) included posture and foam posturography. Items with kappa values between 0.70-0.79 (good) included postural stability, toe walk, and arm swing. Items with kappa values between 0.60-0.69 (good- fair) included rising from a chair and turning 360 degrees. Items with kappa values between 0.50-0.59 (fair) included standing feet together eyes open, heel walk, gait, single limb stance, tandem stance, and number of steps for fast walk. The remaining

items had kappa scores between 0.40-0.49 (fair), specifically turning 180 degrees, modified POMA gait, tandem walk, and number of steps normal speed. The item on the Romberg had lower agreement with a kappa of 0.312. Concurrent validity was established by comparing scores on balance items of the GABS with measures from the Pro Balance Master (Neurocom, Clackamas OR), and scores on gait items of the GABS with measures from the GAITRite, always using Spearman's rho correlations. All balance items on the GABS, with the exception of rise from chair, postural stability, posturography and provocative testing, correlated significantly ($r=0.55-0.64$, $p<0.01$) with maximum excursion left front. Maximum excursion to the left correlated significantly with balance single leg, tandem stance, 180 degree turn, and toe walking ($r=0.55-0.62$). Postural stability correlated with reaction time and maximal velocity measures on the Balance Master, not maximal excursion and directional control measures. The GABS items on postural stability, balance with stance, single limb stance, tandem stance, full and half turn, toe walking and functional reach all correlated significantly with at least one of the Balance Master items. The GABS items rising from a chair, foam posturography, and provocative testing did not correlate with any Balance Master measures (Thomas et al. 2004). Gait, arm swing, gait speed, steps/5m, up and go test, modified POMA (gait), and provocative test had at least one significant correlation with GAITRite measures. Timed tasks correlated most highly with GAITRite measures. Normal and fast speed gait, and the up and go test correlated with mean ambulation time and mean gait velocity on the GAITRite (Thomas et al. 2004). Ten subjects were evaluated ON & OFF PD medications using the GABS. Stand walk sit time and cadence were not significantly different between medication states. Functional reach, gait velocity, and number of steps to walk 10 meters increased significantly, and total GABS score decreased significantly ON medications (Thomas et al. 2004).

SELECTION OF EVALUATION MEASURES

Consensus exists for a multi-factorial evaluation for the person with PD, however there is no agreement as to what should be included (Bloem et al. 2001; Jacobs et al. 2006; Pickering et al. 2007; Landers et al. 2008; Steffen et al. 2008; Schenkman et al. 2011, Leddy et al. 2011). The purpose of the evaluation should always drive selection of tests and measures. Potential needs might include monitoring efficacy of medications, marking disease progression, identifying early falls risk, determining psychometric properties of measures, and finally determining PD specific cutoff points that optimize sensitivity and specificity for existing balance and walking tests (Brusse et al. 2005; Lim et al. 2005; Dibble et al. 2006; Steffen et al. 2008; Landers et al. 2008; Mak et al 2009a; Mak et al. 2009b; Foreman et al. 2010; Leddy et al. 2011). The next question needs to be what is the disease severity, and what measures are sensitive and responsive enough to detect change at each stage (Behrman et al. 2002; Dibble et al. 2006; Landers et al. 2008; Song et al. 2009; Foreman et al. 2010; Schenkman et al. 2011)? Even though H&Y scale and UPDRS total or section scores are most often selected to measure severity, they may not be sensitive enough to detect change in early disease. While performance ON medications might be associated with effectiveness of pharmacological management of the disease, performance during medications fluctuations, or OFF medications, might better reflect typical state, or disease progression respectively (Foreman et al. 2010). Additionally, in order to test ON & OFF PD medications in a single day, it is impossible to randomize order of testing, and OFF medications has to be tested first (Foreman et al. 2010; Bryant et al. 2011). More recently clinicians have begun to question the ecological validity of test batteries; specifically does the evaluation match real world tasks and environments (Foreman et al. 2010; Salarian et al. 2011)? Another debate in the evaluation arena is performance testing versus self-report questionnaires, or the

combination of both. Performance measures have been found to be more sensitive to early disease manifestation than disability (Tanji et al. 2008). Discordance between patients' subjective reporting of function and objective measurements are common, specifically, patients with early PD under rate their disability, while patients with advanced disease over estimate their disability (Shulman et al. 2006; Tanji et al. 2008; Landers et al. 2008). Others have questioned whether evaluations should be limited to factors that can be changed with available therapeutic interventions (Landers et al. 2008). Needless to say the evaluation needs to be tailored to time, space, and equipment constraints. Finally it is unlikely that the UPDRS or the MDS-UPDRS will be replaced as the gold standard evaluation in PD clinical practice by most physicians, despite its limitations for design of an individualized therapy plan of care (Tanji et al. 2008; Song et al. 2009; Goetz et al. 2011). It is essential that measures are reliable, valid, responsive, and sensitive to change. It is desirable to know the minimal detectable change, or smallest detectable difference that has clinical implications. Table 1 compares inter-rater and intra-rater reliability, internal consistency and minimal detectable change of common evaluation tools. Table 2 summarizes sensitivity, specificity, likelihood ratio, and post-test probability of common balance and gait measures.

Table 1: Reliability and Minimal Detectable Change for Existing Balance & Gait Measures

Measure	Author & year	Test-retest reliability	Inter-rater reliability	Minimal detectable change
Berg balance scale	Leddy 2011	0.79 SPT 0.80 PT	0.95	
Berg balance scale	Steffen 2008	0.94		5 points
Berg balance scale	Lim 2005	0.87	0.74	2.84 points
Functional reach test	Steffen 2008	0.73		9 centimeters
Functional reach test	Brusse 2005	0.86		
Functional reach test	Lim 2005	0.87	0.64	11.5 centimeters
Backward functional reach	Steffen 2008	0.67		7 centimeters
Backward functional reach	Brusse 2005	0.87		
Timed up & go	Huang 2008	0.80		3.5 seconds
Timed up & go	Steffen 2008	0.85		11 seconds
Timed up & go	Lim 2005	0.88	0.85	1.63 seconds
Timed up & go	Morris 2001	0.99/0.99 off/on PT 0.87/0.99 off/on student PT		
BESTest	Leddy 2011a, b	0.88 PT 0.91 student PT	0.96	
Dynamic gait index	Huang 2008	0.84		2.9 points
Functional gait assessment	Leddy 2011a, b	0.91 PT 0.80 student PT	0.93	
Activities specific balance confidence scale	Steffen 2008	0.94		5%
Comfortable walking speed	Steffen 2008	0.96		0.18 meters/second
Comfortable walking speed	Lim 2005	0.81 speed 0.88 step freq	0.87 speed 0.80 step freq	0.19 meters/second speed 13 steps
Comfortable walking speed	Brusse 2005	0.90		
Fast walking speed	Steffen 2008	0.97		0.25 meters/second
Fast walking speed	Brusse 2005	0.94		

Table 2: Sensitivity and Specificity of Measures

Test (points)	Author	Cut-off	Sensitivity	Specificity	Area under curve	Likelihood ratio positive & (95% CI)	Likelihood ratio negative & (95% CI)	Post test probability less & (95% CI)	Post test probability more & (95% CI)	Positive predictive value	Negative predictive value
Berg balance scale	Leddy 2011	47	72	75		2.83 (1.69-4.73)	0.38 (0.2-0.72)	56.3	14.6		
		52	92	47		1.74 (1.32-2.30)	0.17 (0.04-0.66)	44.2	7.1		
Berg balance scale (56)	Landers 2008	43.5	68	95.8	0.851	16.19	0.33	99.4			
Berg balance scale (56)	Dibble 2006	54	79	74		3.07 (1.88-5.03)	0.29 (0.17-0.50)				
Functional reach	Dibble 2006	31.75	86	52		1.79 (1.31-2.45)	0.30 (0.15-0.59)				
Functional reach	Behrman 2002	24.5	30	92				90	3	90	36
Performance oriented mobility assessmt. (28)	Kegelmeyer 2007	20	76	66		2.25 (1.64-3.1)	0.37 (0.2-0.67)	91 (82-96)	39 (27-51)		
		23	85	53		1.8 (1.4-2.3)	0.29 (0.13-0.65)				
Timed up & go	Dibble 2006	7.95	93	30		1.31 (1.08-1.59)	0.27 (0.09-0.75)				
Cognitive timed up & go	Dibble 2006	8.5	93	35		1.42 (1.15-1.77)	0.23 (0.18-0.61)				
BESTest	Leddy 2011	≤69%	84	76		3.49 (2.11-5.77)	0.21 (0.09-0.52)	61.3	8.7		
		≤84%	1.00	39		1.64 (1.32-2.02)	0.00	42.7	0.0		
Mini BESTest	Leddy 2011	≤63%	88	78		4.03 (2.4-6.79)	0.15 (0.05-0.45)	64.7	6.5		
		≤72%	96	47		1.82 (1.4-2.37)	0.08 (0.01-0.59)	45.3	3.7		
Dynamic gait index (24)	Landers 2008	18.5	68	70.8	0.758	2.33	0.45	70.8			
Functional gait assessmt (30)	Leddy 2011	15	72	78		3.24 (1.86-5.65)	0.36 (0.19-0.69)	59.6			
		27	1.00	19		1.23 (1.08-1.39)	0.00	35.8			
Sensory	Landers	68.5	60	62.5	0.626	1.6	0.64	62.5			

organization test	2008										
Activity specific balance confidence scale	Mak 2009a,b	69	93	68							
Activity specific balance confidence scale	Landers 2008	75.6	84	62.5	0.763	2.24	0.26	70			
Comfortable walking speed	Landers 2008	1.37	76	50	0.612	1.52	0.48	61.3			
Berg balance scale	Landers 2008	43.5	68								
Obstacle course	Landers 2008	56.2	73.9	73.9	0.766	2.83	0.35	74.7			
Functional gait assessmt.	Leddy 2011	<15	72	75	0.80	3.24	0.36	59.6	14.1		
UPDRS total	Landers 2008	36.5	70.8	91.7	0.879	8.53	0.32	89.9			
UPDRS mentation	Landers 2008	2.5	91.7	58.5	0.756	2.2	0.14	69.6			
UPDRS ADL	Landers 2008	12.5	83.3	85.7	0.888	5.83	0.20	85.9			
UPDRS motor	Landers 2008	14.5	62.5	70.2	0.726	2.10	0.53	68.6			
UPDRS motor	Mak 2009	32	47	94							
Hoehn & Yahr	Landers 2008	2.75	66.7	75	0.845	2.67	0.44	73.5			

FALLS RISK MEASUREMENT

Identification of persons with PD who are at risk for falling is crucial to prevent injury and its consequences – hospitalization, reduced independence, increased burden, placement in long term care, and reduction in quality of life (Dibble et al. 2006; Landers et al. 2008; Mak et al. 2009a; Mak et al. 2009b; Leddy et al. 2011a; Leddy et al. 2011b). The statistics for falls in PD are outstanding. It is estimated that 33-68% of all patients with PD fall within a one year period, and as many as 25-50% have recurrent

falls (Dibble et al. 2006; Mak et al. 2009a; Mak et al. 2009b). The rate for recurrent falls in patients with PD is 9 times that of a healthy, age-matched individual (Bloem et al. 2001; Landers et al. 2008; Mak et al. 2009a). However, summarizing and interpreting the literature on falls is difficult. The first problem involves retrospective versus prospective identification of persons who fall. Falls rate is typically higher when prospective studies are used, perhaps because of “amnesia for falls” (Bloem et al. 2001; Landers et al. 2008; Mak et al. 2009a; Mak et al. 2009b). While there is consensus for the definition of a fall, coming to rest on the floor or other level unintentionally, there is no agreement about the number of falls needed to be classified as a faller, or what constitutes recurrent falls (Bloem et al. 2001; Dibble et al. 2006; Landers et al. 2008; Mak 2009a; Leddy et al. 2011). There is disagreement both in the time frame for collection of falls data (6 vs. 12 months), and in the number of falls needed to qualify as a faller. A faller in some studies was a person who fell at least once in the past 6 months (Bloem et al. 2001; Behrman et al. 2002). Other studies stretched the follow-up period to 12 months and required a single fall or more to be considered a faller (Landers et al. 2008; Mak et al. 2009a; Mak et al. 2009b). Two studies required 2 or more falls in a single year to be designated as a faller (Dibble et al. 2006; Peretz et al. 2006). Participants were labeled as recurrent fallers if they fell 2 or more times in a 6-12 month period in most studies (Bloem et al. 2001; Peretz et al. 2006; Mak et al. 2009a; Leddy et al. 2011a; Leddy et al. 2011b). Table 3 shows differences in falls between patients with PD who fall, and healthy control subjects who fall.

Table 3 Difference in Types of Falls between Patients with PD who Fall and Healthy Control Subjects (modified after Bloem 2001)

Variable	Patients with PD who fall	Healthy controls
Location of fall	Indoors	Outdoors
Type of fall	Center of mass displacement Turning 24% Moving sit to stand 15% Leaning forward 16%	Base of support slips and trips
Cause of falls	Intrinsic Mobility Strength Cardiovascular endurance Dizziness (orthostasis) Freezing of gait	Extrinsic Environmental hazards
Energy type falls	Low energy – walk more slowly reach forward less and less likely to climb to reach	High energy – walk more quickly and more likely to fall from a height
Number of falls	Recurrent falls	Single fall

Prediction of falls risk in PD has been a critical issue on research agendas for the past 10 years. One of the early models suggested that the combined history of a previous fall, disease severity, and score on Romberg test could predict falls risk with a sensitivity of 65% and specificity of 98% (Bloem et al. 2001). Identification of a future faller from a history of a previous fall alone had a sensitivity of 76.5% and a specificity of 74.2%. Given the history of a previous fall, persons with PD had a 6 fold increased risk for a single future fall, and a 9 fold risk for recurrent falls (2 or more), compared with age-matched healthy controls (Bloem et al. 2001). A study of 59 persons with PD, 39% with a previous history of falls, followed prospectively for 6 months, had a single fall rate of 50%, a recurrent falls rate of 25%, and an injurious falls rate of 35% (Bloem et al. 2001). The risk for falling in PD follows an inverted “U” pattern with respect to H&Y stage, slowly building from stage 1 up to 2.5, when dopaminergic medications can overcome movement difficulty, peaking at stage 3 when postural instability which is dopamine resistant sets in, and then falling off in stage 4 when mobility deficits can no longer be controlled by medications. Persons in H&Y stages 1-1.5 had a 13.4 fold increased risk for falls, and persons in H&Y stage 3 had a 100 fold increased risk for falls (Bloem et al.

2001). The retropulsion test, the single item to measure balance in the motor section of the UPDRS, had poor sensitivity, fair accuracy (area under receiver operator characteristic curve = 0.62), and good specificity for falls prediction in PD (Bloem et al. 2001). Similarly, standing tandem with eyes closed had poor predictive ability for falls due to low sensitivity, and was a task that many older adults could not perform. Tandem gait and turning around were items found to have moderate to good sensitivity and specificity for falls prediction (Bloem et al. 2001). Walking and talking simultaneously was no more difficult for those with a history of falls than for control subjects, and was thus not recommended in falls prediction evaluations. The need to examine multi-tasking as opposed to dual task testing was proposed (Bloem et al. 2001). While it was suggested that falls risk might be more accurately predicted if the patient were evaluated OFF medications, Bloem did find that 2/3rd of all falls occurred when the patient reported good medication control, with or without dyskinesia (Bloem et al. 2001).

Does fear of falling lead to increased risk for falls, or does a fall lead to increased fear of falling? It is known that fear of falling leads to restriction of activities, decreased mobility, cardiovascular deconditioning, loss of muscle mass, depression, and decreased quality of life (Bloem et al. 2001; Adkin et al. 2006; Ashburn et al. 2007; Mak et al. 2009). It is hypothesized that immobilization plays an important role in the pathway between fear of falling and falls (Bloem et al. 2001; Mak et al. 2009). Fear of falling is greater in persons with PD who fall (45.8%), compared with healthy control subjects who do not fall (7.4%) (Bloem et al. 2001). Similarly restriction of activity is higher in persons with PD who fall (44.1%), than control subjects who do not fall (11.1%) (Bloem et al. 2001). More persons with PD who fall, have difficulty performing multi-task activities (57.4%) compared with age-matched controls (6.3%) (Bloem et al. 2001). Fear of falling is also more common in PD patients with recurrent falls (52%) than PD patients

who fall only once (22.9%) (Bloem et al. 2001). Finally difficulty performing multiple tasks simultaneously, is more common in PD patients with recurrent falls (73.3%) than single falls (26.4%) (Bloem et al. 2001). Recurrent fallers also were more likely to use a walking aid (35.3%) than single fallers (7.3%) (Bloem et al. 2001).

The contribution of fear of falling to risk for future falls came into question early in the 2000's. Fifty eight patients with PD, and 30 age-matched control subjects performed the ABC scale, UPDRS postural instability gait dysfunction (PIGD) index (items 27-30) and 8 balance challenges while sway of the center of pressure (COP) was recorded on a force plate (Adkin et al 2003). There was a significant difference in test scores on the ABC scale between the groups, with the PD patients scoring mean and standard deviation of 68.7 ± 2.2 , and the controls 93.2 ± 1.3 . The ABC score was significantly related to the PIGD index ($r^2=0.81$, $p<0.001$). PIGD regression scores did not adequately predict center of pressure sway measurements alone, however, when the ABC fear of falling scores were added, over 50% of the variance in COP sway on 5 of 8 balance tests was explained (Adkin et al. 2003). A study that used a dichotomous yes/no question to identify patients with PD with fear of falling, showed that fear of falling alone was independently associated with future falls (Ashburn et al. 2007). Discriminant function analysis was used to determine the relative strength of each of a group of variables in discriminating between faller and non-faller group membership. Four items listed in descending order of importance were found to contribute to the unique effects – UPDRS ADL section, BBS, UPDRS motor section and DGI. The UPDRS ADL section score, H&Y stage, BBS, ABC, and DGI, again in descending order of contribution, contributed to the shared effects (Landers et al. 2008). Seventy one patients with PD (predominantly in H&Y stage 3 and with a falls rate of 46%, and 45 age-matched controls were selected to examine the relationship between fear of falling (ABC scale),

balance (one leg stance test), and functional mobility (TUG), with falling. Univariate regression removed one leg stance from the falls prediction model. After controlling for age, gender, disease duration, and depression, TUG scores greater than 16 seconds, and ABC scores less than 69% independently predicted recurrent falls (Mak et al. 2009b). Stepwise discriminant analysis examined the relative relationship of fear of falling (ABC scale), balance (UPDRS motor section), and functional mobility (TUG) with falls in the group of patients and controls described immediately above (controlling for age, gender, disease severity, and depression). After adjusting for falls history (step 1) and balance (step 2), the final model showed that fear of falling alone predicted recurrent falls. Scores equal to or lower than 69% on the ABC scale had a sensitivity of 93% for predicting recurrent falls in the next 12 months, however specificity was low at 68% (Mak et al. 2009a). A cutoff of 32 on the motor section of the UPDRS yielded a sensitivity of 47% and a specificity of 94%. In order to avoid missing a person at risk for falls, use of the UPDRS motor section in addition to the ABC was recommended. Together the two tests had a sensitivity of 93%, a specificity of 86% and an accuracy rate of 80% (Mak et al. 2009a). Table 4 compares performance of persons with PD who fall with performance of healthy control subjects on common balance measures. Table 5 compares performance of persons with PD who fall, with performance of persons with PD who do not fall on common measures of balance and walking. Table 6 summarizes differences in performance on higher level balance tasks between persons with PD who fall and those who do not fall. Table 7 compares persons with PD who fall a single time with those who fall 2 or more times. Table 8 examines differences in gait parameters ON & OFF PD medications and Table 9 summarizes dynamic balance measures ON & OFF PD medications.

Table 4: Difference in Performance in Common Balance and Gait Measures in Persons with PD who Fall and Healthy Control Subjects who Do Not Fall

Test (maximal score)	Author & year	PD subjects who fall – mean ± standard deviation	Healthy control subjects who do not fall – mean ± standard deviation	P value, effect size (ES) or area under curve (AUC)
Berg balance scale (56)	Dibble 2006	46.4 ± 8.79) 95% CI 43.21-49.87	54.69 ± 1.69 95% CI 53.96-55.42	p<0.001
Functional reach test	Behrman 2002	27.5 ± 8.5 centimeters	33.4 ± 4.9 centimeters	p<0.001
Functional reach	Dibble 2006	23.11 ± 8.12 centimeters 95% CI 20.22-26.42	31.75 ± 5.61 centimeters 95% CI 29.26-34.11	p<0.001
Timed up & go	Dibble 2006	13.71 ± 6.02 s 95% CI 11.38-16.05	9.66 ± 3.18 s 95% CI 8.27-11.03	p<0.001
Timed up & go- OFF medications	Foreman 2010	15.5 ± 11.03 s	8.13 ± 2.34 s	ES = 0.16 AUC = 0 .80
Timed up & go ON medications	Foreman 2010	12.21 ± 7.42 s	7.94 ± 2.15 s	ES = 0.11 AUC = 0.68
Cognitive timed up & go	Dibble 2006	21.45 ± 13.79 s 95% CI 16.10-26.80	11.29 ± 3.92 s	p<0.05
Dynamic gait index (24)	Dibble 2006	17.92 ± 4.36 95% CI 16.23-19.62	21.82 ± 3.42 95% CI 21.02-22.63	p<0.01
Functional gait assessment (30) OFF medications	Foreman 2010	13.67 ± 6.93	22.50 ± 3.63	ES = 0.38 AUC = 0.89
Functional gait assessment (30) ON medications	Foreman 2010	18.77 ± 8.38	26.29 ± 2.33	ES = 0.24 AUC = 0.81
UPDRS motor OFF medications (108)	Foreman 2010	27.79 ± 7.96	25.36 ± 9.99	
UPDRS motor ON medications (108)	Foreman 2010	17.00 ± 8.07	11.57 ± 0.43	

Table 5: Differences between PD Patients Who Fall and Do Not Fall on Balance & Gait Tests

Author & Year	Number Fallers Non-fallers	Functional Reach (centimeters) mean \pm standard deviation	Berg Balance Scale mean \pm standard deviation	Timed Up & Go (s) mean \pm standard deviation	Cognitive Timed Up & Go (s) Mean \pm standard deviation	Tandem stance 30 (s) mean \pm standard deviation
Ashburn 2001 Medians	N=63 F= 40 NF=23	Significant 16.8 22.7		16 14		
Behrman 2002	N=43 F= 30 NF= 13	27.5 \pm 8.5 33.4 \pm 4.9				
Dibble 2008	N=70 F=36 NF=34	Significant 18.33 \pm 3.27 23.88 \pm 3.24	40.8 \pm 8.96 50.0 \pm 3.97	Significant 13.71 \pm 6.02 9.66 \pm 3.15		
Bryant 2008	N=14 F=11 NF=3	Significant 23.1 33.8		Significant 24 11.4		
Dibble 2006	N=45 F=25 NF=20	Significant 23.1 \pm 8.12 31.7 \pm 5.61	46.4 \pm 8.79 54.7 \pm 1.69	Significant 12.19 \pm 5.55 9.50 \pm 6.21	Significant 21.45 \pm 13.79 11.29 \pm 3.92	
Balosh 2005	N=350 F=161 NF=189	Significant 16.8 \pm 10.1 11.2 \pm 5.2				Significant 24.3 \pm 8.9 77.2 \pm 10.3
Robinson 2005	N=40 F=19 NF=21	Significant 25.73 \pm 7.52 29.44 \pm 7.01		Significant 28.07 \pm 16.99 20.33 \pm 3.75	Visual 35.72 \pm 22.83 25.29 \pm 7.83 Motor F=21.86 \pm 5.91 NF=22.05 \pm 4.2	
Foreman 2010	N=36 F=22 NF=14 F=22 NF=14			Significant OFF meds 15.5 \pm 11.03 8.13 \pm 2.34) ON meds 12.21 \pm 7.4) 7.94 \pm 2.15)		

F – Fallers NF – Non-fallers

Table 6: Differences between PD Patients Who Fall and Do Not Fall on Higher Level Balance & Gait Tests

Author & year	Number of subjects	Dynamic gait assessment	Functional gait assessment	Five step test	Postural instability gait dysfunction index	Turn 360 degrees
Bryant 2008	N=14 F=11 NF=3			12.5 9.4	6.3 4.3	5.0 2.7
Foreman 2010	N=36 F=22 NF=14		OFF meds 13.67 \pm 6.93 22.50 \pm 3.63 ON meds 18.77 \pm 8.38 26.29 \pm 2.33			
Dibble 2006	N=45 F=25 NF=20	17.92 \pm 4.36 21.82 \pm 3.42				

F – Fallers NF – Non-fallers

Table 7: Differences between Recurrent and Non-recurrent Fallers in PD

Test	Author & year	Non-recurrent fallers	Recurrent fallers	Significance level
Timed up & go	Mak 2009	13.6 ± 3.1 seconds	18.3 ± 8.8 seconds	Not significant
Activities specific balance confidence scale	Mak 2009	71.9 ± 14.9%	54.4 ± 15.9 %	P<0.001
Performance oriented mobility assessment (balance)	Bloem 2001	1.7 ± 2.50	5.1 ± 2.8	P<0.001
Performance oriented mobility assessment (gait)	Bloem 2001	1.0 ± 1.8	3.8 ± 2.4	P<0.001
Performance oriented mobility assessment (total)	Bloem 2001	2.7 ± 4.0	8.9 ± 4.6	P<0.001
Tandem stance –eyes open (seconds held)	Bloem 2001	52 ± 53.6 s	15 ± 88.2 s	P<0.05
Tandem stance – eyes closed (seconds held)	Bloem 2001	16 ± 16.5 s	9 ± 52.9 s	P<0.01
Romberg (number having difficulty)	Bloem 2001	0	3 ± 17.6	P<0.005
Tandem walk 10 meters	Bloem 2001	19 ± 20.2	10 ± 62.5	P<0.001
Walk & turn 180 degrees	Bloem 2001	26 ± 27.1	12 ± 70.6	P<0.001
UPDRS motor section	Mak 2009 Bloem 2001	21.4± 8.9 17.1 ± 16.6	29.4 ± 9.1 34.8 ± 12.5	P=0.003 P<0.001
UPDRS total score	Bloem 2001	26.5 ± 24.7	52.8 ±17.9	P<0.001
H&Y scale	Mak 2009 Bloem 2001	2.8 ± 0.5 2.1 ± 0.6	3 ± 0.3 2.8 ± 0.6	P=0.031 P<0.001

Table 8: Studies on Differences in Gait Parameters in Parkinson's disease ON & OFF PD Medications

Author and Year	Number of Subjects	Gait Velocity – usual speed meters/second mean ± sd	Gait Velocity Fast meters/second mean ± sd	Cadence (steps/minute) mean ± sd	Stride/ step Length (m) mean ± sd	Double Limb Support (% gait cycle) mean ± sd
Protas & Suteerawattananon 2008	PD=17	OFF: 0.81 ± 0.13 ON: 0.87 ± 0.21	OFF : 1.18 ± 0.27 ON: 1.16 ± 0.31	Usual speed OFF: 121 ± 15.5 ON: 113 ± 13.9 Fast speed OFF: 1.37 ± 0.21 ON: 1.48 ± 0.23	Step Length Usual Speed OFF: 0.41 ± 0.09 ON: 0.5 ± 0.08 Fast speed OFF: 0.52 ± 0.09 ON: 0.48 ± 0.08	
Morris et al. 2003	N=24 PD=12 Control= 12	C: 1.51 ± 0.15 PD OFF: 0.94 ± 0.20 PD ON: 1.25 ± 0.09		C: 124.1 ± 12.6 PD OFF: 118.3 ± 15.3 PD ON: 118.4 ± 14.3	Stride C: 1.46 ± 0.08 PD OFF: 0.96 ± 0.19 PD ON: 1.26 ± 0.10	C: 18.5 ± 2.3 PD OFF: 24.7 ± 4.8 PD ON: 19.3 ± 3.3
Protas & Suteerawattananon 2008	N=9 all PD	Walk 5 m to left: OFF: 11.78 ± 4.78 s ON: 9.33 ± 3.61 s Walk 5 m to right: OFF: 11.86 ± 2.78 s ON: 9.11 ± 3.28 s				

Table 9: Differences in Dynamic Balance Measures ON & OFF PD Medications (Modified from Bryant et al. 2008)

Balance Test	Off PD Medications mean ± sd	On PD Medications mean ± sd
5 step test (s) mean ± sd	13.19 ± 2.02	11.43 ± 2.63
Turn 360 degrees to right (s) mean ± sd	Time in sec: 6.48 ± 4.65 Number of steps: 12.85 ± 11.17	Time in sec: 4.62 ± 2.73 Number of steps: 7.22 ± 2.54
Turn 360 degrees to left (s) mean ± sd	Time in sec: 6.48 ± 4.65 Number of steps: 11.66 ± 6.08	Time in sec: 4.55 ± 2.57 Number of steps: 7.22 ± 2.54

SELECTING AN EVALUATION MEASURE ACROSS THE CONTINUUM OF PARKINSON'S DISEASE

The constraints of clinical practice require that a physical therapist select examination measures that will generate the most relevant information for diagnosis, prognosis, and generation of a patient specific plan of care. Measures must be responsive to the stage of PD disease severity. It is known that even patients in the earliest stages of PD have some early performance deficits when compared with age-matched healthy normal persons (Schenkman et al. 2011). Two studies help shed some insight about which measures can detect differences between the stages of disease severity and disability. Schenkman examined patients in H&Y stages 1-3 and attempted to set performance expectations for patients with PD across the continuum of the disease, both for H&Y stages, and UPDRS motor section scores (Schenkman et al. 2011). Tanji examined patients across H&Y stages 1-5 on 8 physical performance measures, and attempted to identify the measures that distinguished between disability and disease severity quartiles (Tanji et al. 2008). These are presented below.

Schenkman and colleagues aimed to identify benchmarks for functional ability in the patient with PD across the continuum of early to mild disease severity, and to provide clinicians with a framework to interpret examination findings (Schenkman et al. 2011). Baseline data from 339 subjects, evaluated either in Boston or Denver as part of a larger interventional research study, was used in the current study. The only inclusion criteria were H&Y stage 1-3, ambulatory, and living in the community. The samples from the two sites were not significantly different in age (mean and standard deviation 66.1 ± 9.3 years), gender (70.6% male), race (96% Caucasian), UPDRS motor score (mean and standard deviation 25.2 ± 9.56), H&Y score (56% were in stages 2.5-30), mini mental status examination (mean and standard deviation 29.1 ± 1.03); however, there were

significant differences in time since onset (mean and standard deviation 6.0 ± 5.12 years), UPDRS total score (mean and standard deviation 39.2 ± 12.93), and UPDRS ADL score (mean and standard deviation 11.8 ± 5.23). Participants were classified into one of 4 H&Y stage groups (H&Y 1-1.5, H&Y 1.5-2, H&Y 2-2.5 and H&Y 2.5-3), and one of 4 UPDRS motor section score range groups (0-15, 15.5-30, 30.5-45 and 45.5-60). Schenkman characterized what clients in each of the 4 H&Y stage groups and each of the 4 UPDRS motor section groups would score on three categories of common balance and gait measures - 1. functional capacity, 2. balance and gait, and 3. basic functional activity measures. The continuous scale physical functional performance test (CS-PFP) was the only measure in the functional capacity category. The balance and gait category measures included - functional reach test (FRT), timed up and go (TUG), 360 degree turns, 2 minute walk test (2MWT) and 6 minute walk test (6MWT). The basic functional activity category measures included - functional axial rotation (FAR) and the supine to stand/stand to supine tests. The CS-PFP is a 15 item test, where items are performed sequentially without a rest, and timed from the start of item 1 to the end of item 15. Rate of perceived exertion is rated at the conclusion of the test. Items included but were not limited to low energy items like donning and doffing a jacket and pouring a glass of water from a pitcher, moderate energy items like sweeping the floor and moving items from washing machine to dryer, and high energy items like carrying groceries 70 meters and walking up and down a bus platform carrying a suitcase. The CS-PFP dropped approximately 10 points between each range of the UPDRS motor scores until range 45.5-60, where the drop was 20 points (range 0-15, score 59.88; range 45.5-60, score 20.93). This pattern of dropping continuously until the final stage was repeated with the H&Y stages (stages 1-1.5, score 62.90; stage 2.5-3, score 28.67). The rate of perceived exertion held steady over the initial 2 H&Y stages and UPDRS motor score ranges, and

then increased steadily. The FRT dropped steadily over both UPDRS motor score ranges and H&Y stages, approximately 6 inches from slight to moderate disease. Time to complete the TUG increased approximately 2.5 seconds steadily across each H&Y stage and UPDRS motor range, from a start of 8 seconds. Time to turn 360 degrees did not drop at regular increments across H&Y stages or UPDRS motor score ranges, and in fact seemed to drop more between the two final stages/ranges, however the difference between highest and lowest scores was only 2 seconds and 4 steps. Patients in H&Y stage 3 took twice as long to complete the 360 turn than those in stages 1-1.5 (7.34 seconds versus 3.33 seconds; 6.33 steps versus 11.04 steps). Six minute walk distance and speed dropped most quickly between H&Y stages 2 and 2.5, and between UPDRS motor scores 30-45 and 45.5-60 (approximately 100 meters for distance and 0.20 meters/second for velocity). Those who were least involved walked approximately 560 meters at a velocity of 1.60 meters/second, compared to those most involved, who walked about 395 meters at a velocity of about 1.10 meters/second both for H&Y stages and UPDRS motor score ranges. Two minute walk time and velocity dropped off at irregular intervals, but mostly between H&Y stages 2.5 and 3 (40 meters and 0.35meters/second). While no data was available for H&Y stage 1-1.5, those with mild disease walked 167.65 meters at an average gait velocity of 1.40 meters/second, compared with those with moderate disease, who walked only 118.10 meters at an average velocity of 0.98meters/second. Turning to UPDRS motor score ranges, there was an irregular decline in both distance walked and average velocity; however, again the greatest decline was between UPDRS motor scores of 30.5-45 and 45.5-60 (approximately 20 meters and 0.17 meters/second), followed by that between UPDRS motor scores 0-15 and 15.5-30 (approximately 13 meters and 0.11meters/second). Mean distance walked was 168.86 meters for the least involved group and 128.40 meters for the most involved group. Average gait velocity was 1.41

meters/second for the least involved group and 1.07 meters/second for the most involved group. The mean and median did not behave the same way for change in time to move supine to standing across H&Y stages and UPDRS motor stages. Whereas the greatest decline in mean time took place between H&Y stages 2.5-3 (approximately 2 seconds), and there was marked difference in time between H&Y stages 2 and 2.5 (approximately 1.3 seconds), median scores dropped most between H&Y stages 2 and 2.5 (approximately 1.7seconds). There was no clinically significant decline in H&Y scores until stage 2.5. The time to move supine to standing was 3.35 seconds for the least involved subjects and 6.42 seconds for the most involved subjects. The mean and median drop in supine to stand times for UPDRS motor scores ranges was greatest between 30.5-45 and 45.5-60 (approximately 3 seconds for the mean and 1.3 seconds for the median). Time to move from supine to standing for those least involved was 2.79 seconds for the mean and 2.72 seconds for the median compared to time for the most involved which was 6.55 seconds for the mean and 4.5 seconds for the median. The mean FAR declined most between H&Y stages 2 and 2.5 (approximately 9 degrees). Trunk rotation scores for the least involved H&Y stages were 103.5 degrees and declined to 86.5 degrees for those in H&Y stage 2.5-3. Those in UPDRS motor score group 0-15 had FAR scores of 107.61 compared with those in the group 45.5-60 whose score averaged 75 degrees (Schenkman et al. 2011).

A study was designed to compare physical performance measures for their ability to discriminate between levels of disability and disease severity in Parkinson's disease (Tanji et al. 2008). Seventy nine persons with PD were tested on several measures, specifically the physical performance test (PPT), modified physical performance test (mPPT), short physical performance battery (SPPB), performance test of activities of daily living (PADL), Berg balance scale (BBS), timed up and go (TUG) and functional

reach (FRT). The sample could be described as follows: mean and standard deviation for age was 65.5 ± 2.6 years; 57% were male; H&Y stages ranged from 1-5 with 5 persons (6.3%) in H&Y stage 1, 47 patients (59.5%) in H&Y stage 2, 13 persons (16.5%) in H&Y stage 3, 9 persons (11.4%) in H&Y stage 4 and 5 persons (6.3%) in H&Y stage 5. Scores were reported by H&Y stage and by mean and standard deviation for the entire group. Thirty to 34 subjects performed each test, and there were no significant differences in age, gender, H&Y stage, or total UPDRS scores between those assigned to each test. The mean score and standard deviation for the UPDRS was 42.9 ± 19.8 ; for the PPT 19.5 ± 5.4 ; for the MPPT 20.2 ± 6.9 ; for the SPPB 8.4 ± 3.8 ; for the PADL 95.39 ± 39.6 ; for the BBS was 48.4 ± 14 ; for the TUG 12.3 ± 5.3 seconds; and for the FRT 8.5 ± 2.9 inches. The scores were well distributed for all measures with the exception of the BBS and PADL where there were ceiling effects. An analysis of quartiles derived from Kruskal-Wallis tests showed that 4 of the 7 measures significantly discriminated across disability quartiles of the Older Americans Resource and Services (OARS) – PPT, mPPT, BBS and TUG. All 7 measures discriminated across quartiles of disease severity on the total UPDRS score. Five measures discriminated across quartiles of the motor UPDRS score – PPT, SPPB, PADL, TUG and FRT. All 7 measures showed a significant worsening performance moving from best to worst quartiles of disease severity (OARS) ($p < 0.05$). Post hoc analysis using Mann-Whitney tests, revealed significant differences between selected quartiles of disability on the OARS for 5 measures – PPT, MPPT, SPPB, BBS, and TUG. Differences between quartiles of disease severity (total UPDRS) were demonstrated for all measures with the exception of the PADL. Five measures discriminated between quartiles of the motor UPDRS- PPT, SPPB, BBS, TUG, and FRT. TUG and mPPT were the only measures that were able to discriminate between lower levels of disability. Four measures discriminated between lower levels of the motor

UPDRS – PPT, BBS, FRT, and TUG. Two measures discriminated between lower levels of the total UPDRS – PPT, mPPT. Six out of 7 measures discriminated between subjects with H&Y stage 2 versus H&Y stage 2.5/3 – TUG ($p<0.001$), SPPB BBS and FRT ($p<0.01$) and mPPT ($p<0.05$). PADL did not discriminate between subjects with and without postural instability. All 7 performance measures were more strongly correlated with disease severity (UPDRS, and H&Y stages) than disability (OARS). Of interest SPPB, BBS and TUG correlated significantly with all measures of disability and disease severity. Of these, the BBS had the strongest correlations with all disability and disease severity measures ($r=0.55-0.74$, $p<0.001$). Four measures correlated significantly with all disease severity measures (UPDRS and H&Y), but not with disability measures (OARS) – PPT, mPPT, PADL, and FRT (Tanji et al. 2008).

Another strategy to select evaluation measures is to see how well different balance measures correlate with measures of disease severity (UPDRS and H&Y) and with each other. Although studies reviewed were all cross-sectional in design, if measures show a strong association, it may be possible to eliminate measures that duplicate data for clinical decision making. Table 10 summarizes correlations between existing measures. It is important to consider the overlap of items between the different measures since a high correlation may occur simply because items are the same. Table 11 compares items on the most common balance and gait tests. Of all the measures the BESTest correlated most strongly with disease severity measures (UPDRS $r=-0.758$, mH&Y $r=-0.758$), self-perceived measures of balance (ABC $r=0.707$), and the BBS ($r=0.873$) (Leddy et al. 2011). Nevertheless there are 27 items on the BESTest, and it takes at least 30 minutes to administer. The FGA also correlated strongly with disease severity measures (mH&Y $r=-0.670$, UPDRS $r=0.692$, UPDRS motor $r=0.699$), self-perceived measures of balance (ABC $r=0.707$) and the BBS ($r=0.783$) (Leddy et al.

2011). The FGA is much shorter to administer (approximately 10 minutes) than the BESTest. It is of interest that even though there is no walking component to the BBS, it correlates highly with the FGA ($r=0.783$), TUG ($r=-0.78$), comfortable walking speed ($r=0.73$) and fast walking speed ($r=0.64$) (Brusse et al. 2005; Leddy et al. 2011). The FRT also correlated strongly with comfortable walking speed, suggesting that there is an association between movements of the center of body mass over the base of support and walking. Comfortable and fast walking speeds have an excellent correlation ($r=0.89$) (Brusse et al. 2005). The ABC scale has a strong correlation with the newer MDS-UPDRS ($r=0.726$), but is not as strongly associated with the older UPDRS ($r=-0.523$) (Leddy et al. 2011).

Table 10: Correlation between Balance and Gait Measures

Author	Test	M H&Y	UPD RS total	UPD RS motor	BBS	FRT	TUG	POM A	BES Test	Mini BES Test	ABC	FGA	CWS	FWS
King 2012	UPDRS				r= 0.76 p< 0.001			r= 0.76 p< 0.001			r= 0.64 p< 0.001			
King 2012	i-TUG steps turn		r= 0.37 p= 0.001		r= 0.33 p< 0.001			r= 0.41 p= 0.001			r= 0.22 p= 0.14			
King 2012	i-TUG turn duration		r=0.24 p= 0.11		r= 0.31 p= 0.03			r= 0.38 p= 0.01			r= 0.23 p= 0.13			
King 2012	i-TUG turn velocity		r=0.45 p= 0.002		r=0.39 p= 0.007			r= 0.41 p= 0.004			r= 0.36 p= 0.02			
King 2012	i-TUG total time				r= 0.48 p= 0.001			r= 0.71 p= 0.001			r= 0.47 p= 0.001			
Leddy 2011	ABC	r= - 0.591 p< 0.01	r= - 0.523 p<0.01 MDS - UPDRS r= - 0.726 p< 0.001		r= 0.638 p< 0.001						r=1			
Leddy 2011	BBS	r= - 0.629 p< 0.001	r= - 0.710 p< 0.001		r=1						r= 0.638 p< 0.001			
Leddy 2011	FGA	r= - 0.670 p< 0.001	r=0.692 p< 0.001	r= 0.699 p< 0.001	r= 0.783 p< 0.001						r= 0.707 p< 0.001	r=1		
Leddy 2011	BEST-est	r= - 0.736 p< 0.001	r= - 0.758 p< 0.001		r= 0.873 p< 0.001				r=1		r= 0.707 p< 0.001			
Song 2009	CWS		r=0.522 p< 0.001 UPDRS - ADL r= 0.386 p=0.04	r= 0.453 p= 0.012									r=1	
Song 2009	FWS		r=0.544 p= 0.002	r= 0.563 p= 0.001										r=1
Song 2009	Sit to stand		r=0.565 p= 0.001	r= 0.552 p= 0.002										
Tanji 2008	UPDRS total		r=1		r= - 0.74 p< 0.001	r= - 0.69 p< 0.001	r= 0.67 p< 0.001							

Tanji 2008	UPDRS ADL				r= -0.65 p< 0.001	r= -0.45 p< 0.05	r= 0.52 p< 0.001							
Tanji 2008	UPDRS Motor		r=1		r= -0.59 p< 0.01	r= -0.66 p< 0.001	r= 0.66 p< 0.001							
Tanji 2008	M H&Y	r=1			r= -0.74 p< 0.001	r= -0.71 p< 0.001	r= 0.71 p< 0.001							
Kegel-meyer 2007	POMA total			r= -0.45 p< 0.05				r=1					r= 0.53 p< 0.01	
Kegel-meyer 2007	POMA Balance			r= -0.40 p< 0.05									r= 0.52 p< 0.01	
Kegel-meyer 2007	POMA Gait			r= -0.43 p< 0.05									r= 0.50 p< 0.01	
Qutubu d-din 2005	BBS	r= -0.45 p< 0.005			r=1									
Qutubu d-din 2005	UPDRS motor	r= -0.42 p< 0.05		R=1	r= -0.58 p< 0.005									
Qutubu d-din 2005	M H&Y	r=1		r= -0.42 p< 0.05	r= -0.45 p< 0.005									
Lim 2005	CWS				r= 0.56 p< 0.001								r=1	
Lim 2005	TUG		r=0.75 p< 0.001				r=1							
Brusse 2005	TUG		r= -0.50 p< 0.05	r=0.58 p< 0.01	r= -0.78 p< 0.001		r=1							
Brusse 2005	BBS		r= -0.64 p< 0.001	r= -0.69 p< 0.001	r=1		r= -0.78 p< 0.001						r= 0.73 p< 0.001	r=0.64 p< 0.001
Brusse 2005	FRT forwd		r= 0.52 p<0.05	r= -0.45 p<0.05	r=0.50 p<0.05	r=1	r= -0.20 p> 0.05						r= 0.21 p> 0.05	r= 0.13 p> 0.05
Brusse 2005	FRT backwd		r= -0.39 p> 0.05	r= -0.33 p> 0.05	r=0.51 p<0.05		r= -0.35 p> 0.05						r= 0.63 p< 0.001	r= 0.43 p< 0.05
Brusse 2005	CWS		r= -0.27 p> 0.05	r= -0.36 p> 0.05	r=0.73 p<0.001								r=1	r= 0.89 p< .001
Brusse 2005	FWS		r= -0.31 p> 0.05	r= -0.32 p> 0.05	r=0.64 p<0.001								r= 0.89 p< 0.001	r=1

Table 11: Comparison of Items between Balance and Gait Measures

Item	BBS	BESTest	GABS	POMA	UPDRS motor	DGI	FGA
Rise from chair	x		x	x	x		
Sit down from standing	x						
Standing posture			x	x	x		
Stand feet together eyes open	x	x	x	x			
Stand feet together eyes closed	x	x	x	x			
Stand foam/non-firm surface eyes open		x					
Stand foam/non-firm surface eyes closed		x	x				
Functional reach forward	x	x	x				
Functional reach lateral		x					
Stand on one leg	x	x	x				
Tandem stance	x		x				
180 degree turn with or without walking		x	x	x		x	x
360 degree turn	x		x	x			
Alternate foot touch step	x	x					
Lateral lean trunk		x					
TUG		x	x				
Cognitive TUG		x					
Transfer – level surfaces	x						
Stand and look over shoulders	x			x			
Walking level surface normal speed		x	x	x	x	x	x
Walk level surface fast speed/ or speed up when walking			x			x	x
Walk with head turns lateral			x			x	x
Walk with head turn up & down			x			x	x
Walk on toes			x				
Walk on heels			x				
Walk & step over obstacle		x				x	x
Walk tandem			x			x	x
Walk- quality factors			x	x	x	x	x
Walk around obstacles						x	
Walk in narrow space			x				x
Walk backward							x
Retropulsion			x		x		
stairs						x	x

The measures selected to evaluate the patient with PD should change over the continuum of disease severity. At the beginning it is important to identify measures that distinguish clients with PD from age-matched healthy controls. Two such measures include functional axial rotation (FAR) and the clinical scale physical function performance (CS-PFP) (Schenkman et al. 2011). The critical factor in the CS-PFP is that several tasks are performed sequentially and timed, rather than allowing the patient to stop between tasks. Axial rotation of the trunk is compromised early in PD, well before the client starts to notice difficulty with walking and arm swing, and difficulty with bed mobility tasks. It is still not clear whether segmental dissociation of upper and lower

body is detected with the FAR. Finger tapping has been examined as an option to distinguish patients with PD from control subjects (Macleod et al. 2010). Timed motor tasks have been suggested as a method for distinguishing between persons with PD and age matched control subjects (Haaxma et al. 2010; Macleod et al. 2010). One hundred and thirty eight patients with PD, and 158 age matched controls performed a finger tapping task, moving the finger between two counters placed 30 centimeters apart, for a duration of 30 seconds (Macleod et al. 2010). The average of two attempts with each hand was used as the score. Secondly they performed a TUG with the walking distance of 6 meters rather than the usual 3 meters. The group with PD was significantly younger than the control group, and 8% of the group with PD had mini mental status scores less than 24 compared with 1.3% in the control group. The control group was entirely male and the PD group was 57% male. The persons with PD were not taking any dopamine or dopamine agonists. Median score and inter-quartile range(IQR) for the UPDRS motor section was 2(0-5) for the control group, 25(17-32) for the group with PD, and these scores were significantly different. Age and gender influenced performance of finger tapping. As age increased, number of finger taps decreased. Males performed better than females (but there were less females overall). In both the control and PD groups, participants performed significantly more finger taps with their dominant than non-dominant hands. Subjects in the control group completed 46 ± 4.5 taps in 30 seconds with their dominant hand, and 45 ± 13 taps with their non-dominant hand. The participants with PD performed 30 ± 11 finger taps with their dominant hand, and 28 ± 10 with their non-dominant and/or more affected hand. Ninety five percent confidence intervals were established with the control group. For the dominant hand the interval was 18-74, and only 9% of the persons with PD fell outside this range. For the non-dominant hand the interval was 17-72, and only 9% of persons with PD fell outside this range. For this

reason the finger tapping task was not recommended as a test to distinguish persons with and without PD (Macleod et al. 2010). Similarly the median score and IQR for the 6 meter TUG was 15 (13-17) for the control group, and 19 (15-24) for the group with PD. The 95% confidence interval was 9-27, and again only 17% of patients with PD fell outside this range, suggesting that this test could not adequately distinguish patients with PD from control subjects (Macleod et al. 2010). Another study examined whether a timed motor test (TMT) battery, that consisted of 8 subtasks based on aspects of walking, writing, finger tapping, single and double peg board performance, and diadochokinesis could differentiate between newly diagnosed dopamine naive persons with PD and age matched control subjects (Haaxma et al. 2010). The psychometric properties of the TMT were determined previously, and it was shown to have good reliability, validity, and feasibility; the TMT correlated well with the UPDRS motor section (Haaxma et al. 2010; Bloem et al. 2008). The TMT was thought to be more responsive than the UPDRS motor section. One hundred seven persons with PD and 100 control subjects were recruited to perform the TMT. The pegboard dexterity test had a sensitivity of 95%, a specificity of 89%, and an area under the curve (AUC) for the receiver operator characteristic (ROC) curve of 0.97 for persons with PD, compared with healthy controls. Since this was the only subtask that had such high sensitivity and specificity, the authors recommended that it replace the entire battery (Haaxma et al. 2010). Forty two of the persons with PD had unilateral involvement, specifically a score of 0 on the UPDRS motor section for one side. Their non-affected limb performance was compared with that of age matched control subjects on the pegboard dexterity test. While the accuracy was not as high (AUC=0.73), the pegboard dexterity test retained its sensitivity and specificity. A cutoff of ≥ 10 seconds would have a high specificity 94% but a sensitivity of 33%. A cutoff of ≥ 9 seconds would have a sensitivity of 83% and a specificity of 51% (Haaxma et al. 2010).

The authors concluded that the pegboard test is inexpensive and sensitive and might be appropriate as a diagnostic tool in clinical practice to assess patients with early PD symptoms (Haaxma et al. 2010).

Inherent in the current research agenda for PD is the search for biomarkers to identify pre-clinical disease, so that neuroprotective strategies can be implemented before there is irreversible change in the dopamine system and its projections. Unfortunately, all studies examining measures to identify motor dysfunction in the newly diagnosed patient with PD are under-populated with patients in H&Y stage 1 particularly, and to a lesser extent stage 1.5 (Haaxma et al. 2010; Macleod et al. 2010). In this earliest stage of PD, pegboard dexterity tests might be the earliest tool to detect bradykinesia; however, there are a large number of persons with PD who present with tremor as the first symptom (Haaxma 2010). A finger tapping task was not sensitive enough to discriminate between those with early PD and healthy control subjects. Functional axial rotation (FAR) does show differences between those in the earliest stages of PD, but this study was under-populated at H&Y stage 1. This was also the case for the CS-PFP (Schenkman et al. 2011). The biggest drop in the FAR occurs between H&Y stages 2 & 2.5 (Schenkman et al. 2011). The biggest drop in CS-PFP occurs between H&Y stages 2.5-3 (Schenkman et al. 2011). The 6 minute walk test is not adequate to detect endurance problems early on in PD (Schenkman, et al. 2011). Similarly the TUG, even with a 6 meter walking distance, is not diagnostic for early PD (Macleod et al. 2010).

A critical transition point along the continuum of PD is the move from stage 2, where there is no postural instability, to stage 2.5 where there postural instability begins. Several measures are known to distinguish between H&Y stages 2 and 2.5 (Tanji et al. 2008; Schenkman et al. 2011). The physical performance test (PPT), modified PPT, short physical performance battery (SPPB), BBS, TUG, and FRT were all able to distinguish

persons with PD in H&Y stage 2 from those in stage 2.5/3 (Tanji et al. 2008). As mentioned above the FAR drops the most between stages 2 and 2.5 and the 6 minute walk time is significantly different between these two stages. The supine to stand median declines the most between the stages in consideration, and clinical difficulty with turning in bed may become evident (Schenkman et al. 2011). Another critical transition point is between H&Y stages 2.5 and 3. Postural instability begins in H&Y stage 2, but the client still has the movement diversity to execute balance strategies that are effective under everyday circumstances. At stage 3 the postural instability increases and falls risk peaks, because the client no longer can produce the movements needed for balance and functional mobility. Some evaluations show their biggest change between stages 2.5 and 3, specifically the 2 minute walk time, 360 degree turns, and supine to stand. Additionally the CS-PFP mean makes its greatest drop at this time, and persons in stages 2.5-3 often score below 57, the cutoff score for the transition from independence to dependence in activities of daily living (Schenkman et al. 2011). The SPPB, BBS (especially items 1-10), TUG and FRT were suggested for use in advanced PD (Tanji et al. 2008).

There are several gaps in the literature suggested by this review. It is thought that the UPDRS might be more effective in measuring impairment and disease severity, than in measuring functional outcomes and participation limitations. This being said, it is important to identify which measures of function are not being addressed, and determine the best way to measure them. Nobody has correlated balance and gait measures in patients with PD with the UPDRS, both when the client is ON & OFF PD medications. Similarly nobody has determined the degree to which individual balance measures correlate with each other. If the correlation is high, measures may be redundant, and clinicians might be able to limit their evaluations to those providing unique data. Second, PD- specific tests of balance and gait predicted fallers and non-fallers in a group of

patients with PD, better than non-specific tests, with the exception of the BBS. Perhaps a balance measure, specific to PD, that incorporates components of the BBS TUG and FRT, like the GABS, might better predict falls risk and cutoff level. Third, nobody has examined whether self-perceived measures of balance (ABC) correlate with performance measures of balance. It is clear that a battery of tests is needed to adequately measure the multi-dimensionality of balance, however there is insufficient data on which measures to use, which are redundant, and which could be eliminated. Fourth, nobody has used instrumented gait analysis to more precisely measure specific gait parameters other than gait velocity, specifically cadence and stride length, that are known to be impaired in PD. Nor has anybody compared velocity, stride length, and cadence, as measured by instrumented gait analysis, with the same variables measured when walking over ground, both at comfortable and fast speeds in patients with PD. Nor has anybody looked at backward walking as a potentially important gait assessment in PD. Finally, nobody has correlated specific gait parameters like stride length and cadence with the UPDRS-total score or motor score. Thus the purpose of this study is first to determine the degree to which specific measures of gait and balance correlate with the UPDRS total score and with the motor section of the UPDRS, and second to measure the degree to which different balance and gait measures correlate with each other.

Chapter 3: METHODS

This study is part of a larger multicenter study on Gait and Step Training to Prevent Falls in Parkinson's Disease. In the larger interventional study patients were followed over a one year period. They began with a screening evaluation where their balance, gait, posture, coordination, motor control, depression, fatigue, and activity level were measured both in the OFF medication and ON medication states. This evaluation was followed by a 5 month period of recording falls and their circumstances. Patients were instructed to send in postcards each time they fell and each fall was followed up with a phone call to determine the circumstances and injuries. Subjects were called weekly to determine whether they fell as a backup to the postcards. The subjects repeated the extensive evaluation battery prior to training and were screened for cardiovascular ability to perform exercise. Patients were randomized into one of two training groups and trained 3 times per week for 8 weeks for a total of 24 sessions. The first group was gait and step training which consisted of multi-directional gait training on a treadmill (with a harness), walking faster than over ground speed. Then they performed sudden stops and starts of the treadmill, again multidirectional. The second group did stretching in sitting followed by aerobic training on the arm ergometer and leg bicycle in sitting. Total training time for both groups was one hour. At mid-training a brief evaluation was completed, and the same intensive evaluation that was performed at screening and pre-training was performed at the end of training as well as 1 and 5 months later. During the five months after training, falls and their circumstances were again collected by postcards and weekly calls. This current study used data from the initial screening evaluation. This study was approved by the Research Division Institutional Review Boards of the

University of Texas Medical Branch, the Michael E. DeBakey Veteran's Administration Medical Center in Houston, and Baylor University.

SUBJECTS

There were two sites for the Gait and Step Training to Prevent Falls in Parkinson's Disease - University of Texas Medical Branch (UTMB) in Galveston, and the Michael E. DeBakey Veteran's Administration Medical Center in Houston (VA). Subjects were recruited from the neurology clinics at UTMB, the VA, and at the Baylor Movement Dysfunction Clinic. After a short presentation on the study, packets with study information were left with all residents in neurology at UTMB and at the Michael E. DeBakey VA Medical Center. Subjects from the neurology clinic in Galveston were evaluated and treated in Galveston, and subjects from the VA were evaluated and treated in Houston. Subjects from the Baylor Movement Dysfunction Clinic were evaluated and treated in the study site closest to their home. Visits were made to all physicians in Galveston County and southeast Harris County who treated patients with PD, and packets with study information were left with each of them. Additionally subjects were recruited from local PD support groups and the Houston Ballet dance group for persons with PD. Ads were placed in local newspapers to recruit additional subjects. Inclusion criteria for this study included: 1) diagnosis of Parkinson's disease by a physician; 2) postural instability and gait dysfunction type of PD; 3) history of falls and postural instability with or without freezing of gait and a positive retropulsion or pull test; 4) Hoehn and Yahr stages 2-4; 5) a stable regimen of Parkinson's disease medications; 6) able to walk without assistive device for short distances, at least 5 meters; 7) no other neurological orthopedic, cardiovascular or pulmonary condition that would limit walking; 8) scores of moderate or higher in all domains of the Neurobehavioral Cognitive Examination

(cognistat); and 9) sufficient comprehension of English and hearing to follow directions and respond to questionnaires. Exclusion criteria included: 1) predominantly rigidity or tremor type of PD; 2) cardiovascular or pulmonary conditions which would exclude participation in exercise training; 3) musculoskeletal and orthopedic conditions that would limit ability to walk and perform exercise; 4) inadequate comprehension of English to follow directions and respond to questionnaires; 5) participation in another exercise or physical therapy program; and 6) scores lower than mild dysfunction on more than two domains of the Neurobehavioral Cognitive Examination (Cognistat). This current study examined data from the initial screening evaluation for the first 92 subjects enrolled at the two centers. Each subject was tested for gait, balance, and functional level both ON & OFF PD medications. Participants took their evening PD medications but did not take their morning PD medications; hence they were OFF PD medications for a minimum of 12 hours. Subjects were tested first thing in the morning. After completing all testing OFF medications, subjects took their PD medications and waited an hour until they had reached the ON state before testing was repeated.

MEASURES

All measures were made first with the patient in the OFF medication state, and second with the patient in the ON medication state, both in a single morning. The time to complete the balance and gait tests was between 1-1.5 hours for each medication state. During the 1 hour following ingestion of PD medications, paper and pencil data was collected on fatigue, sleepiness, comorbidities, physical activity level, depression and fear of falling. Patients were given the opportunity to sit down and rest whenever necessary, and no subject reported fatigue at any point during the study. A few patients performed

the OFF medications testing one morning and the ON medications testing the next day. These subjects either had more advanced disease, greater co-morbidities or advanced age.

Disease severity measures: The UPDRS is the most frequently used instrument to measure disease severity in PD. It consists of 4 subscales, section I mentation behavior and mood, section II activities of daily living (ADL), section III motor examination and section IV complications of therapy. Each item in sections I-III of the UPDRS is scored on a 5 point ordinal scale ranging from 0-4. Lower scores correspond with a less involved disease process. There are 4 items in section I resulting in scores ranging from 0-16; there are 13 items in section II resulting in scores ranging 0-52; there are 12 items in section III motor examination; however, some items are rated for multiple areas of the body and some for left and right sides, thus scores range from 0-108; section IV complications of the disease has some items rated using the 0-4 scale, and others rated on a yes/no dichotomy, however scores from section IV are not used to calculate the total score. The total score (range 0-176) is derived by summing scores on sections I-III. The Movement Disorder Society recommends that the patient self-score sections I&II and that the physician or therapist score sections III&IV (Movement Disorder Society, 2003). The internal consistency of the UPDRS total score, as measured by Cronbach's alpha is reported to be 0.96, the mentation behavior and mood section 0.79, the ADL section 0.85- 0.92 and the motor examination section 0.88-0.95 (Stebbins et al. 2008). The test-retest reliability of the UPDRS, as measured by intra class correlation coefficient, is reported to be 0.92 for the total score, 0.74 for the mentation behavior and mood section, 0.85 for the ADL section and 0.90 for the motor score (Siderowf et al. 2002). The UPDRS subscales were administered as described by Goetz and colleagues (Goetz et al. 1996). Both physical therapists collecting the UPDRS data reviewed the UPDRS teaching videotape.

Balance measures: Balance measures included the 5 step test, timed 360 degree turns, the gait and balance scale (GABS), and the Postural Instability Gait Dysfunction (PIGD) Index. In addition we measured the patient's self-perceived balance confidence using the paper and pencil Activity Specific Balance Confidence Scale (ABC). For the **5 step test** the subject was asked to step up and down an 8.8 centimeter high step 5 times as quickly and safely as possible while being guarded for safety. We recorded time in seconds to perform 5 steps, hence better performance is reflected by lower times. This test has been reported to be reliable in elderly subjects without neurological deficits (Murphy MA, Olson S, et al. 2003). The intra class correlation for inter-rater reliability for the 5 step test was 0.997, and the intra class correlation for test-retest reliability was 0.967 (data from the first 12 participants in Galveston). **Turning speed** was assessed by timing a 360 degree turn performed twice to each side. The tester demonstrated the turn, and then asked the subject to turn as quickly and safely as possible while being timed. The average time in seconds to turn 360 degrees of the two trials in each direction was calculated as the definitive score. Number of steps to turn 360 degrees for each trial was also recorded and averaged for the two trials in each direction. This test has been reported to be reliable in individuals with PD (ICC=0.95 for test-retest reliability) (Suteerawattananon et al. 2000). **The Gait and Balance Scale** was designed to measure gait, freezing of gait, the gait cycle, as well as balance and posture (Thomas et al. 2004). There are two parts to the scale; the first is a historical section that consists of questions related to walking, level of care, activities of daily living, falls, limitation of activity due to fear of falling, and frequency of freezing of gait. This section was modeled on the ADL scale of the UPDRS. The second part consists of performance of 14 items of balance and gait including posture, postural stability, 360 degree and 180 degree turns, Romberg test (standing with feet together with arms folded across the chest first with the

eyes open and then with the eyes closed), tandem stance, single limb stance, provocative tests for freezing, foam posturography, a modified gait section of Tinetti's Performance Oriented Mobility Assessment (POMA), walking on heels, walking on toes, walking tandem, and the FRT. Although not part of the total score, the TUG, and timed comfortable and fast walking speed were also measured. Items are derived from the UPDRS, BBS, FRT, TUG, and POMA. Items 1-17 are scored on a scale of 0-4 (with higher scores indicating worse performance). Items 18-24 are scored on a scale of 0 to 1 or 0-2 (0 being normal and 2 being worst). Total scores range from 0-93. Inter-rater reliability calculated using Cohen's Kappa Statistic was high, with $k > 0.41$ for 17 items and $k > 0.61$ for 6 items (Thomas et al. 2004). Concurrent validity was established comparing the GABS with instrumented gait assessment using the GAITRite, and with computerized measures of limits of stability on the Balance Master, using Spearman's rho test. Posture, pull test, balance during stance, single limb stance, tandem stance, turning, toe walking and FRT had a significant correlation with the Balance Master scores ($r = 0.46-1.00$, $p < 0.01$). Similarly gait, arm swing, gait speed, 5 step test, TUG, modified POMA and provocative testing had a significant correlation with GAITRite measures ($r = 0.51-0.83$, $p < 0.01$) (Thomas et al. 2004). The **PIGD index** is a subset of five items from sections II and III of the UPDRS, specifically 13) falling unrelated to freezing, 14) freezing when walking, 28) posture, 29) gait and 30) postural instability. These items reflect factor 1 of the UPDRS - axial function, gait, and balance (Stebbins et al. 1998). There have been no specific tests of test-retest reliability or inter rater reliability for the PIGD index. However since it is derived from the UPDRS, which has been shown to have test-retest and inter-rater reliability, and since its items represent a single factor of the UPDRS, it is likely that the PIGD index is also reliable. There is evidence to show that a client's perception of their balance during a variety of activities,

well as their fear of falling, is associated with falls rate (Wolf et al. 1996). Therefore we had participants complete the **Activities Specific Balance Confidence (ABC) Scale** to provide an estimate of overall balance self-efficacy (Powell LE et al. 1995). The ABC requires participants to rate the degree of confidence they have in completing 16 basic and instrumental activities of daily living. The scale includes both walking and reaching-oriented activities that challenge postural control, and also includes activities performed both indoors and outdoors. This scale ranges from 0% (no confidence) to 100% (complete confidence). The mean ABC score across all 16 items was used to estimate the degree or level of confidence in balance. People with PD report lower balance confidence compared to healthy age-matched controls; mean scores of the posture and gait items (walk around house, walk up and down stairs, walk outside to a nearby car, walk around a parking lot, walk up and down a ramp, walk in crowded mall, walk in crowd and be bumped, ride escalator holding and not holding rail, and walk on icy sidewalks) correlate with the UPDRS total score ($R^2=0.81$; $p<0.01$) and mean scores of the balance specific items (pick up slipper from floor, reach at eye level, reach while on toes, stand on chair to reach, sweep the floor, and get in and out of car) correlate with the UPDRS total score (range of R^2 was 0.18-0.34; $p<0.01$) (Suteerawattananon et al. 2000). The ABC has been shown to be both reliable and valid in elderly persons with postural instability (Powell LE et al. 1995; Myers et al 1997).

Gait measures: We used a portable gait analysis system (GAITRite, Cir Systems, Havertown PA) to measure **stride length**, the length in centimeters for two consecutive footfalls of the same extremity, **cadence**, the number of steps per minute, and **gait velocity**, the time in seconds that it takes to walk down the 5 meter long walkway. Gait velocity can also be calculated multiplying stride length times cadence. Typically as PD progresses both gait velocity and stride length decrease significantly, but it is thought that

stride length reduction contributes more to the reduced gait velocity than cadence (Morris et al. 2003). The GAITRite is a portable, computer-based instrumented electronic roll-up walkway connected to a personal computer, with application software for the calculation of temporal and spatial aspects of gait. The walkway is 5 m long with a pressure sensitive mat (61x366) composed of a series of sensors, organized in a 48x288 grid pattern, sandwiched between two layers of vinyl. The patient stands at the end of the mat before beginning a trial and walks off the far end of the mat. Data is recorded from the middle portion of the mat to avoid acceleration and deceleration at the beginning and end of the walk. The subject's leg length is measured bilaterally from the greater trochanter to the lateral malleolus, and entered into the system along with age, gender, height, weight, and shoe size. As a subject walks across the mat, data from the triggered sensors is collected by on-board processors connected in series, and fed into the computer through a serial port (19,200 baud). The patient was asked to walk without an assistive device along this instrumented 5 meter walkway while being guarded by a physical therapist for safety. Participants walked along the walkway, forward at their usual speed, forward at their fastest speed, and backward at a safe self-selected speed. We recorded stride length of each leg as well as cadence and gait velocity. The subject completed two trials at each speed and in each direction, and the average of the results from the two trials was used as data. Temporal and spatial parameters measured on the GAITRite have been reported to be reliable (ICC>0.93) and valid (ICC>0.93) (Cutlib et al. 2000; McDonough et al. 2001). Gait speed has also been reported to be a reliable measure in patients with PD with intra class correlation coefficients of 0.87 for test-retest reliability (Schenkman et al. 1997). We also measured **timed gait** walking over ground, a distance equal to the length of the 5 meter GAITRite mat, with the subject walking forward at a self-selected/comfortable walking pace, forward at a fast pace, and backward at a fast but safe

pace. A distance of 5 meters was marked on the floor with colored tape. Timing began when the subject crossed the initial line and ended when the subject crossed the second line. Time was measured in seconds. The instructions for the comfortable speed walking were to walk all the way down the floor beyond the second line at a comfortable speed without slowing down until after the line is crossed. The instructions for fast speed walking were to walk all the way down the floor beyond the second line as fast and safely as possible without slowing down until after the second line is crossed. The instructions for backward walking were to walk backward down the floor beyond the second line at usual speed and as safely as possible without slowing down until after the second line is crossed. Two trials at each speed and in both directions were averaged. Test-retest reliability intra class correlation coefficients for comfortable and fast walking forward in patients with PD have been reported to be above 0.90, and inter-rater reliability above 0.96 (Brusse et al. 2005; Steffin et al. 2008). In order to calculate gait velocity for over ground non-instrumented walking, the walkway length 5 meters was divided by the time in seconds to traverse the distance. **Cadence** (steps per minute) was calculated by dividing the steps to walk 5 meters by the time to go 5 meters in seconds, and multiplying this by 60 to convert to steps per minute. **Average stride length** (meters/stride) was calculated as the product of the 5 meter distance divided by the number of steps to complete the course and multiplied by 2 since there are 2 steps in each stride. This calculation does not allow you to differentiate stride length for the left and right legs as is done on the GAITRite. Therefore we averaged GAITRite stride length for the left and right sides to compare with the non-instrumented over ground stride length.

Subject Characteristics: Researchers collected demographic information, as well as information on the onset and course of the PD, disease duration, co-morbidities, medications and dosage (both those for PD and those for other health conditions), and

body mass index (weight/height squared). Subjects were asked to recall the number of falls they experienced in the past 6 months, and to give their perception of why they fell. They were asked to recall the details of the falls – activity they were performing at the time, presence of dyskinesias or freezing, presence of motor fluctuations and OFF medication status, direction of fall, time of day of the fall, presence of dizziness or sleepiness, lighting and floor surface conditions, as well as footwear worn at the time of the fall. Cognitive status was determined by the Neurobehavioral Cognitive Status Examination (Cognistat), a 10 item reliable measure of cognitive status in elders and in patients with neurological dysfunction (Kiernan et al. 1992).

TESTING PROTOCOL

Subjects arrived first thing in the morning, usually between 8:00 and 8:30 am, and informed consent was obtained after the participant had the opportunity to ask questions and seek clarification on the details of the study. Each participant had the opportunity to review the consent form in advance of the initial screening evaluation. A licensed neuropsychologist administered and scored the Neurobehavioral Cognitive Examination (Cognistat) to determine whether the patient had sufficient cognitive abilities to meet the inclusion requirements for the study. OFF medications testing began with the participant performing walking trials on the GAITRite forward at usual and fast speeds, and backward at a comfortable and safe speed as described above. This was followed by performance of the timed tests, starting with the 360 degrees to the left and right, then the 5 step test, then side stepping to the left and right and finally backward walking. Two trials of each of the timed tests were performed in each direction and at the two speeds and the average score for each direction and speed was recorded. Additionally we measured number of steps to turn 360 degrees in each direction, walking sideways and

walking backward, and again the average number of steps from the two trials was recorded. It was from this trial of backward walking that the calculations for gait velocity, cadence, and stride length were derived. Participants began the GABS testing by filling in the historical section, specifically questions 1-7. The 14 performance items of the GABS were carried out following Thomas' guidelines, and this was followed by over ground walking at usual and fast speeds and performing the 5 meter TUG (Thomas et al. 2004). Dynamic posturography followed and participants completed the limits of stability test on the Smart Balance Master (Neurocom, Clakamus OR). The final OFF medications evaluation was the completion of the UPDRS. Participants completed sections I & II, and the physical therapist completed sections III & IV as instructed by Goetz (Goetz et al. 2003). In cases where the participant could not read or write the answers alone, the physical therapist read the question and choices to the patient and entered the patient's response. The Hoehn and Yahr rating scale for disease severity, and the Schwab and England activities of daily living tests were completed at the same time as the UPDRS. The patient then took his/her PD medications with water and a light snack. A bathroom break was provided. While the medications were allowed to reach peak dose, the patient completed several paper and pencil tests, specifically the Epworth Sleepiness Scale (Johns 1991), the Iowa Fatigue Scale (Hurtz et al. 2003), the Activities Specific Balance Confidence Scale (Powell et al. 1995), the Center for Epidemiology Depression Scale (Radloff 1977), the Physical Activity Scale for the Elderly (PASE) (Washburn et al. 1993), and the Charlson Comorbidity Index (Charleson et al. 1987). Again the physical therapist was available to help with reading and/or entering the responses indicated by the participant. When it was deemed that the patient was in the ON medications state, either by elimination of symptoms or by verbal report from the patient that he/she felt "ON",

usually 45-60 minutes later, the entire testing process was repeated. Breaks were provided as needed for rest, and again there were no complaints of fatigue during testing.

STATISTICAL ANALYSIS

Demographic information: All data was analyzed using SPSS version 18 (Chicago IL). Demographic data was summarized using descriptive statistics. During data collection it was determined that some of the older version GAITRite software version 3.3 walks could not be migrated to the GAITRite software version 3.9 as planned, so that all walks could be analyzed using a single GAITRite version. This GAITRite software version 3.3 data was collected from the first 23 subjects at the Michael E. DeBakey Veteran's Administration Hospital in Houston. Therefore descriptive data was reported separately for Galveston, the first 23 subjects at the VA, and subjects 24-59 at the VA. Continuous data from the three groups (age, years since onset, height and weight, Charleson Comorbidity Index) was analyzed using a one way analysis of variance, with a Tukey correction for post hoc testing. Hoehn & Yahr stage off and on, and falls category were analyzed using the Kruskal Wallis test. There was no need to analyze nominal data (living situation, marital status, and vocation) since participants were overwhelmingly married, living with their spouse and retired.

Specific aim 1 was to determine which clinical measures of balance and gait in PD correlate, both ON & OFF PD medications, with the UPDRS total score and the UPDRS motor score, since the UPDRS is the gold standard measure of disease severity. *Hypothesis 1* was that there would be a positive relationship (Spearman's $\rho \geq 0.70$) between the 5 step test, timed 360 degree turns in each direction, the gait and balance scale (GABS) and the postural instability gait dysfunction index (PIGD) with the *total* score of the UPDRS both ON & OFF PD medications. To test this hypothesis, we

estimated Spearman's rank correlation coefficients (Spearman's rho) between each balance measure and the UPDRS total score, first when the patient was OFF PD medications, and then when the patient was ON PD medications. The Spearman's rho correlation coefficient was selected since the UPDRS was one of the measures. The UPDRS is scored on a 0-4 scale where higher scores indicate increased disease severity. There is no evidence to support that the distance between adjacent scores for each item are equal. The UPDRS does not utilize a fixed set of anchors from item to item, thus the identical score on two items might not reflect the same functional limitation (Schenkman et al. 2010). Since the distribution of the Spearman's rho is unknown, and since Spearman's rho correlations are close to Pearson's product correlations, we decided to use a one-sided Fisher's Z transformation on the Spearman's rho correlations to test the hypothesis that the correlation between each balance test and the UPDRS total score was > 0.5 , with alpha set at 0.05. The null hypothesis was that Spearman's rho correlation between each balance test and the UPDRS total score, transformed with a Fisher's Z, was ≤ 0.5 with alpha set at 0.05. The alternative hypothesis was that $\rho > 0.50$. Our sample size was 89, so this gave us power > 0.9 if rho was 0.7. All testing was conducted using Fisher's Z transformation:

$$Z = \sqrt{89-3} \{ \ln[(1+r)/(1-r)] - \ln[(1+.5)/(1-.5)] \} / 2 = 4.68 \{ \ln[(1+r)/(1-r)] - \ln(3) \}$$

where r is Spearman's rho. If $Z > 1.96$ we declared r to be significantly greater than 0.5.

We also performed a univariate regression analysis with the UPDRS in each medication state as the dependent variable, and the balance measures as the independent variables. This allowed us to determine the degree to which the different balance measures predicted variability in UPDRS total scores.

Our second hypothesis was that there would be a positive relationship (Spearman's rho $r=0.7$) between the 5 step test, timed 360 degree turns, GABS, and PIGD index and the *motor section score* of the UPDRS both ON & OFF PD medications. To test this hypothesis we estimated the Spearman's rho correlations of each balance measure and the motor examination UPDRS score, first when the patient was OFF PD medications, and then when the patient was ON PD medications. Since the Spearman's rho is close to the Pearson product correlation, and since the distribution of the Spearman's rho is unknown, we used a one-sided Fishers Z transformation to test the hypothesis that the correlation between the given balance test and the UPDRS motor score was > 0.5 with alpha set at 0.05. The null hypothesis was that the correlation between the balance measure and the UPDRS motor score transformed by a one sided Fisher's Z was ≤ 0.5 with alpha set at 0.05. The alternative hypothesis was that $\rho > .50$. Our sample size was 89, so this gave us power >0.9 if rho was 0.7. All testing was conducted using the Fisher's Z transformation equation above. If $Z > 1.96$ we declared r to be significantly greater than 0.5.

Our third hypothesis was that there would be a negative relationship (Spearman's $r < 0.70$) between GAITRite and overground measures of velocity, cadence, and stride length during forward, fast forward, and backward walking, with the *total* score of the UPDRS, both ON & OFF PD medications. To test this hypothesis we estimated the Spearman's rho correlations for each gait measure (velocity, cadence, and stride length) for forward walking at a comfortable pace, forward walking at a fast pace, and backward walking at a fast but safe pace using the GAITRite data and using over ground walking calculations, with the total score of the UPDRS, first when the patient was OFF medications, and second when the patient was ON medications. Since the Spearman's rho and the Pearson product correlation are close, and since the distribution of the

Spearman's rho correlation is unknown, we used a one sided Fisher's Z transformation to test the hypothesis that the correlation between the gait parameter (velocity, cadence, stride length) and the UPDRS total score was > 0.5 with alpha set a 0.05. The null hypothesis was that the correlation between each gait variable and the UPDRS score was ≤ 0.5 with alpha set at 0.05. The alternative hypothesis was that $\rho > .5$. Our sample size was 89, so this gave us power > 0.9 if rho was 0.7. All testing was conducted using the Fisher's Z transformation using the equation above. If $Z > 1.96$ we declared r to be significantly greater than 0.5.

Our fourth hypothesis was that there would be a negative relationship (Spearman $r < 0.7$) between GAITRite and over ground measures of velocity, cadence, and stride length during forward, fast forward and backward walking, with the *motor* score of the UPDRS, both ON & OFF PD medications. To test this hypothesis we calculated the Spearman's rho correlations for each gait measure (velocity, cadence, and stride length) with the *motor* section of the UPDRS, first when the patient was OFF medications and then when the patient was ON medications. This was done using data from the GAITRite and over ground trials walking forward at a usual speed, walking forward at a fast speed, and walking backward at a safe speed. Since Spearman's rho correlation is close to the Pearson product correlation, and since the distribution of Spearman's rho is unknown, we used a one-sided Fisher's Z transformation to test the hypothesis that the correlation between the gait parameter (velocity, cadence, stride length) and the UPDRS motor section score was > 0.5 with alpha set a 0.05. The null hypothesis was that the correlation between the gait parameter and the UPDRS motor section score was ≤ 0.5 with alpha set at 0.05. The alternative hypothesis was that $\rho > 0.50$. Our sample size was 89, so this gave us a power > 0.9 if rho was 0.7. All testing was conducted using the Fisher's Z

transformation equation above. If $Z > 1.96$ we declared r to be significantly greater than 0.5.

Specific aim 2 was to determine the degree to which performance and self-perceived measures of balance used for patients with PD correlate with each other, both when the patient is ON & OFF PD medications. *Our hypothesis* was that there would be a negative relationship (Spearman's $r < 0.7$) between self-perceived measures of balance (Activities Specific Balance Confidence Scale) (ABC) and performance measures of balance (5 step, timed turning 360 degrees, GABS, and PIGD index) both when the patient was ON & OFF PD medications. To test this hypothesis we estimated Spearman's rho correlations between the ABC and each of the other balance measures first when the patient was OFF PD medications, and second when the patient was ON PD medications. Since the Spearman's rho correlation is close to the Pearson product correlation, and since the distribution of the Spearman's rho is unknown, we used a one sided Fisher's Z transformation on the Spearman's rho correlations to test the hypothesis that the correlation between each performance balance measure (PIGD, GABS, timed turning 360 degrees and 5 step test) and the self-perceived ABC scale was > 0.5 , with alpha set at 0.05. The null hypothesis was that the correlation between the performance balance measure and the self-perceived balance measure was ≤ 0.5 . The alternative hypothesis was that $\rho > 0.5$. Our sample size was 89, so this gave us a power > 0.9 if rho was 0.7. All testing was conducted using the Fisher's Z transformation equation above. If $Z < 1.96$ we declared r to be significantly greater than 0.5.

Specific aim 3 was to determine whether measures for velocity, cadence, and stride length made walking on the GAITRite instrumented walkway and over ground were the same, first with the patient walking forward at a usual pace, second walking

forward at a fast pace and third walking backward at a safe pace, both ON & OFF PD medications.

Hypothesis 1a was that there would be no significant difference between the means for each gait parameter (velocity, cadence, and stride length) measured walking forward at a usual speed on the GAITRite and over ground, both ON & OFF PD medications.

Hypothesis 1b was that the Spearman's rho correlations for each of the gait parameters (velocity, cadence, and stride length) made walking forward at a *usual speed* on the instrumented GAITRite and over ground would be > 0.7 both ON & OFF PD medications.

Hypothesis 2a was that there would be no significant difference between the means for each gait parameter (velocity, cadence, and stride length) measured walking forward at a *fast speed* on the GAITRite and over ground, both ON & OFF PD medications.

Hypothesis 2b was that the Spearman's rho correlations for each of the gait parameters (velocity, cadence, and stride length) measured both ON & OFF PD medications walking forward at a *fast speed* on the instrumented GAITRite and over ground would be > 0.7 .

Hypothesis 3a was that there would be no significant difference between the means for each gait parameter (velocity, cadence, and stride length) measured walking *backward at a safe speed* on the GAITRite and over ground, both ON & OFF PD medications.

Hypothesis 3b was that the Spearman's rho correlations for each of the gait measures (velocity, cadence, and stride length) measured both ON & OFF PD

medications walking *backward at a safe speed* on the instrumented GAITRite and over ground would be > 0.7 .

All three hypotheses were tested in a similar manner, both ON & OFF PD medications, since the only difference was direction or speed of walking. For hypothesis 1-3a we performed paired sample t-tests for each of the gait variables (velocity, cadence, and stride length) to determine whether the mean value measured walking on the instrumented GAITRite walkway and over ground were significantly different. Since variance around the means was high, we decided to examine whether the distributions around the means (as measured by Spearman's rho correlation coefficients) for each for each gait variable measured on the instrumented GAITRite and over ground were the same. For hypothesis 1-3b we estimated Spearman's rho correlations for each of the gait variables (velocity, cadence, and stride length) walking on the instrumented GAITRite and over ground. Since Spearman's rho and Pearson's product correlations are close and since the distribution of Spearman's rho is unknown, we used a one sided Fisher's Z transformation on the Spearman's rho correlations to test the hypothesis that the correlation between each of the gait variables (velocity, cadence, and stride length) measured walking on the instrumented GAITRite walkway and over ground was >0.5 , with alpha set at 0.05. The null hypothesis was that the correlation between each of the gait variables, velocity, cadence, and stride length measured walking on the instrumented GAITRite walkway and over ground was ≤ 0.5 when the Spearman's rho was > 0.7 . Thus if the calculated Z was >1.96 we declared r to be significantly greater than 0.5. With a sample size of 28 in Galveston, we had power >0.7 when rho was greater than 0.7. With a sample size of 22 at the VA Group 1, we had power >0.7 when rho was >0.7 . With a sample size of 34 at the VA Group 2, we had power >0.9 when rho was >0.7 . With a

sample size of 62 in the combined Galveston VA2, we had power >0.9 when $\rho >0.7$. In all cases α was set at 0.05.

Chapter 4 RESULTS

SUBJECTS

Initially 92 subjects were recruited at the two testing sites, 31 in Galveston at UTMB, and 61 in Houston at the Michael E. DeBakey Veterans Administration Hospital and Baylor Movement Disorder Clinic. One subject in Galveston and two subjects in Houston were subsequently excluded when their diagnosis of Parkinson's disease was revised to stroke, pseudobulbar palsy, and Parkinson's plus syndrome respectively. This made them ineligible for the study, but they were removed before any testing was done. Hence 89 subjects ultimately entered into the study, 30 from Galveston, and 59 from Houston. Subjects from Houston were further divided into two subgroups for the gait evaluations. VA Subjects 1-23 (VA 1) performed their GAITRite evaluations on GAITRite software version 3.3. Subjects from Galveston and Houston subjects 24-59 (VA 2) performed their GAITRite evaluations on the GAITRite software version 3.6, 3.8 or 3.9 (Cir Corporation, Havertown PA). Data from the GAITRite software version 3.6 was first migrated to the GAITRite software version 3.8. Then all data from GAITRite software version 3.8 was migrated to GAITRite version 3.9 so that all participant walks were analyzed using a single software system. Unfortunately there was no way to migrate the data from the GAITRite software version 3.3 to the GAITRite version 3.9, hence the need to separate the Houston sample.

Whereas Table 12 summarizes the general demographic information for the participants, Table 13 describes the demographic information related to Parkinson's disease (PD). Across all 3 sites, 56.45% of the subjects were male. While participants in Galveston and Houston VA group 2 were approximately two thirds male, the individuals at the VA group 1 were 88% male, mostly veterans with PD. The subjects were, largely

Caucasian, married and living with their spouse, college-educated, right handed and retired. The groups were equivalent for age, height, and weight, however they differed in time since onset and number of co-morbidities (Charlson Co-morbidity Scale with age removed (Table 14a). The Houston VA group 1-23 had longer disease duration (mean and standard deviation 10.30 ± 6.01) than the other groups (Galveston mean and standard deviation 6.24 ± 4.75 , and Houston VA 2 mean and standard deviation 8.06 ± 5.33). The Charlson Comorbidity Scale total score includes 1 age point for each decade past 40 years. We chose to use the Charlson Comorbidity Scale sub-score with the age points excluded so that what we were measuring was purely comorbidity (Charlson et al. 1997). The subjects in Galveston scored predominantly 5 or 6 on the Charlson Comorbidity Scale, while subjects from Houston scored 4 and 5. Lower scores indicated less comorbidity. Subjects in Galveston had a much higher incidence of gastrointestinal dysfunction, most often constipation. The majority of subjects (approximately 85%) walked independently either without an assistive device or with a cane. The remaining 15% of the participants also walked independently using a rolling walker. Hoehn & Yahr (H&Y) stages for the groups ranged from 1.5-5 OFF medications and 1-4 on medications. The median H&Y score OFF medications was 3 in Galveston and at the VA Group 1 and 2.5 for the VA Group 2. ON medications the median H&Y scale was 2.5 for Galveston and the VA Group 2 and 3 for the VA Group 1. There was no significant difference in H&Y stages between the Galveston participants and the participants in the two VA groups both ON & OFF PD medications (Table 14d). Sixteen percent of the participants in Galveston had not fallen in the six months prior to admission to the study, while 36% of the subjects in Houston had no history of falling. Since the frequency distribution for falls was so skewed, falls were categorized according to the item on falls in the UPDRS, (0=no falls, 1= rarely falls, 2=falls <1/day, 3= falls once a day, and 4 falls >1/day). Table

14c illustrates the falls categories for each site. There was no significant difference in the categories of falls between the participants in Galveston and in the two Houston groups (Table 14d). Table 15 presents information on the subject's associated medical conditions. The most common co-morbidities in the groups were hypertension, urinary dysfunction, and cardiac dysfunction respectively. Table 16 summarizes the Parkinson's disease medications the participants were taking and Table 17 describes the non-PD medications for the groups. Most of the subjects took carbidopa-levodopa along with either a dopamine agonist and/or a MAOB inhibitor. The most common non-Parkinson's medications were for hypertension and hyperlipidemia.

Table 12: Demographic Information Subjects from Galveston & Houston

Data	Galveston	Houston 1-23	Houston 24-59	Houston 1-59
Age (mean \pm sd)	69.52 \pm 9.42	71.89 \pm 7.24	67.78 \pm 7.87	69.42 \pm 8.36
Gender (M/F) (%)	66.67/33.33	82.60/17.40	74.30/28.60	77.60/22.40
Race (%)				
Caucasian	93.33	56.52	75.00	67.78
Hispanic	3.33	13.04	8.33	10.17
African American	3.33	8.70	8.33	8.47
Asian	0.00	13.04	11.10	11.86
Other	0.00	4.34	0.00	1.69
Marital Status (%)				
Married	76.67	82.60	88.89	86.44
Widowed	13.33	8.70	8.33	8.47
Divorced/separated	10.00	8.70	2.78	5.08
Living Arrangement (%)				
Alone	10.00	13.04	0.00	5.17
With spouse	76.67	73.91	97.14	87.93
With family	10.00	4.34	2.86	3.44
With friend	3.33	4.34	0.00	1.72
Assisted Living	0.00	0.00	2.86	1.72
Nursing Home	0.00	4.34	0.00	1.72
Education (%)				
Middle school	6.67	4.34	0.00	1.72
High school	23.33	47.83	31.42	37.93
College	66.67	30.43	54.29	44.83
Graduate degree	3.33	17.39	17.14	17.24
Occupation (%)				
Working /retired	13.33/86.67	0/100	28.57/71.43	15.52/84.48
Dominant Hand L/R (%)	6.67/93.33	0/100	2.78/97.22	1.69/98.31
Weight (mean \pm sd) kilograms	80.44 \pm 17.83	84.09 \pm 29.72	79.32 \pm 17.95	80.98 \pm 21.35
Height (mean \pm sd) centimeters	167.64 \pm 10.06	172.34 \pm 14.38	172.57 \pm 11.08	171.27 \pm 11.08

Table 13: Demographic Variables Related to Parkinson's Disease

Variable	Galveston	Houston(1-23)	Houston (24-59)	Houston (1-59)
Time since onset Mean ± sd (years)	6.42 ± 4.75	10.30 ± 6.01	8.04 ± 4.94	8.06 ± 5.33
Hoehn & Yahr Stage OFF (%)				
1.5	3.00	0.00	2.78	1.69
2	10.00	17.39	11.11	13.56
2.5	33.33	30.43	41.67	37.29
3	46.67	30.43	30.56	30.51
4	6.70	21.74	11.11	15.25
5	0.00	4.35	0.00	1.69
Hoehn & Yahr Stage ON (%)				
1	0.00	0.00	5.56	3.39
1.5	6.67	0.00	2.78	1.69
2	16.67	17.39	22.22	20.34
2.5	36.67	14.00	50.00	54.24
3	10.00	21.74	13.89	16.95
4	6.67	4.35	2.78	3.39
Walking Independence (%)				
Independent	19.00	43.48	58.33	52.54
With cane	23.33	26.09	19.44	13.00
With walker	13.33	17.39	16.67	16.95
Hand held assist	0.00	0.00	2.78	1.69
Wheelchair	0.00	4.35	0.00	1.69
Falls past 6 months (%)				
0	16.67	13.04	50.0	35.60
1	36.67	8.70	19.44	15.25
2	10.00	8.70	2.78	5.08
3	3.33	13.04	2.78	6.78
4	3.33	8.70	0.00	3.39
5	0.00	4.35	5.56	5.08
6-10	6.67	17.39	2.78	8.47
11-20	6.67	21.74	0.00	8.47
21-50	0.00	4.35	16.67	11.86
>50	0.00	4.35	0.00	1.69
Charleson Comorbidity Scale (%)				
1	3.33	0.00	2.78	1.69
2	6.67	4.35	8.34	6.78
3	13.33	8.70	13.89	11.86
4	13.33	26.09	27.78	27.12
5	23.33	26.09	19.44	22.03
6	23.33	8.70	8.34	8.47
7	10.0	8.70	0.00	5.08
8	6.67	4.35	2.78	3.39
9	0.00	4.35	2.78	3.39

Table 14a: ANOVA Demographic Variables

		Sum of Squares	df	Mean Square	F	Sig.
Age (yr)	Between Groups	235.38	2	117.69	1.71	0.187
	Within Groups	5986.57	87	68.81		
	Total	6221.96	89			
Time since onset (yr)	Between Groups	199.31	2	99.65	3.72	0.028
	Within Groups	2302.60	86	26.77		
	Total	2501.91	88			
Height (centimeters)	Between Groups	39.432	2	19.72	0.94	0.394
	Within Groups	1822.85	87	20.95		
	Total	1862.29	89			
Weight (kg.)	Between Groups	1755.19	2	877.60	0.39	0.677
	Within Groups	194794.66	87	2239.02		
	Total	196549.86	89			
Co-morbidity no age (yr)	Between Groups	26.76	2	13.38	8.78	0.000
	Within Groups	129.56	85	1.52		
	Total	156.32	87			

Bold: significant p<0.05

Table 14b: Post Hoc Testing Demographic Variable

Dependent Variable	(I) local		(J) local		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
								Lower Bound	Upper Bound
Time since onset	1.00		2.00	-4.24	1.41	0.009	-7.59	-0.88	
			3.00	-1.98	1.26	0.266	-4.99	1.03	
	2.00		1.00	4.24	1.41	0.009	0.88	7.11	
			3.00	2.26	1.36	0.226	-0.99	5.51	
	3.00		1.00	1.98	1.26	0.266	-1.03	4.99	
			2.00	-2.26	1.36	0.226	-5.51	0.99	
age	1.00		2.00	-2.50	2.31	0.526	-8.01	3.00	
			3.00	1.59	2.06	0.721	-3.32	6.5	
	2.00		1.00	2.50	2.31	0.526	-3.00	8.01	
			3.00	4.09	2.22	0.163	-1.21	9.39	
	3.00		1.00	-1.59	2.06	0.721	-6.5	3.32	
			2.00	-4.09	2.22	0.163	-9.34	1.21	
height	1.00		2.00	-3.08	4.50	0.773	-13.83	7.66	
			3.00	-0.5	4.02	0.992	-10.08	9.09	
	2.00		1.00	3.08	4.50	0.773	-7.67	13.83	
			3.00	2.59	4.34	0.822	-7.76	12.94	
	3.00		1.00	0.5	4.02	0.992	-9.09	10.08	
			2.00	-2.59	4.3	0.822	-12.94	7.76	
weight	1.00		2.00	-1.22	6.07	0.978	-15.71	13.26	
			3.00	1.39	5.42	0.964	-11.53	14.31	
	2.00		1.00	1.22	6.07	0.978	-13.26	15.71	
			3.00	2.62	5.85	0.896	-11.34	16.57	
	3.00		1.00	-1.39	5.42	0.964	-14.31	11.53	
			2.00	-2.62	5.85	0.896	-16.57	11.34	
Comorbidity no age	1.00		2.00	0.95*	0.35	0.022	0.11	1.79	
			3.00	1.19*	0.31	0.001	0.46	1.92	
	2.00		1.00	-0.95*	0.35	0.022	-1.79	-0.11	
			3.00	0.24	0.34	0.757	-0.57	1.05	
	3.00		1.00	-1.19*	0.31	0.001	-1.92	-0.47	
			2.00	-0.24	0.34	0.757	-1.05	0.56	

* The mean difference is significant at the 0.05 level.

Table 14c: Falls Categories across Sites

Falls Category	Galveston	VA Group 1	VA Group 2
0 never falls	7	4	15
1 rare falls	16	9	13
2 falls < 1/day	6	7	8
3 falls 1/day	0	2	0
4 falls >1/day	1	0	0

Table 14d: Kruskal-Wallis Tests Demographic Data

Null Hypothesis	Test	Significance	Decision
The distribution of comorbidity with no age is the same across sites	Independent sample Kruskal Wallis test	0.000	Reject the null hypothesis
The distribution of falls categories is the same across sites	Independent sample Kruskal Wallis test	0.076	Retain the null hypothesis
The distribution of H&Y stage scores OFF medication is the same across sites	Independent sample Kruskal Wallis test	0.169	Retain the null hypothesis
The distribution of H&Y stage scores ON medication is the same across sites	Independent sample Kruskal Wallis test	0.450	Retain the null hypothesis

Table 15: Associated Medical Conditions Galveston and Houston (%)

TIA - transient ischemic attack

Condition	Galveston	Houston 1-23	Houston 24-59	Houston 1-59
Hypertension	43.33	47.82	33.33	38.98
Orthostasis	16.67	26.08	8.33	15.25
Hyperlipidemia	3.33	0.00	5.56	3.39
Cardiac condition	36.67	26.09	30.56	28.81
Peripheral Vascular Disease	6.67	0.00	0.00	0.00
Respiratory	10.00	0.00	8.33	5.08
Previous TIA/CVA	6.67	17.39	0.00	6.78
Diabetes	3.33	4.35	8.33	6.78
Stomach & GI	26.67	0.00	2.78	1.69
Liver	3.33	0.00	2.78	1.69
Thyroid	10.00	8.70	2.78	5.08
Urinary	30.00	39.13	33.33	35.59
Gall bladder	3.33	0.00	0.00	0.00
Cancer	26.67	26.09	16.67	20.34
OA/RA	20.00	4.35	2.78	3.39
THR	3.33	0.00	0.00	0.00
TKR	13.33	0.00	0.00	0.00
Chronic low back pain	3.33	0.00	5.56	3.39
Osteoporosis	0.00	0.00	2.78	1.69
Polio	0.00	4.35	0.00	1.69
Depression	3.33	8.70	0.00	3.39
Dementia	13.33	0	8.33	5.08
Bipolar disease	0.00	4.35	0.00	0.00
Sleep apnea	0.00	0.00	2.78	1.69
Night sweats	0.00	4.35	2.78	3.39

CVA - cerebrovascular accident

GI - gastro-intestinal

Table 16: Parkinson's Disease Medications Galveston and Houston (%)

Medications	Galveston	Houston 1-23	Houston 24-59	Houston 1-59
Carbidopa-levodopa Sinnemet	60.00	91.30	75.0	81.36
Dopamine agonists				
Primapexol (mirapex)	13.33	52.17	33.33	40.68
Ropinerol (requip)	20.00	13.04	30.56	23.73
Bromocriptine	0.00	13.04	8.33	10.17
Amantadine	13.33	13.04	38.87	28.81
COMT inhibitors				
Entacapone (comptan)	6.67	34.78	5.56	16.95
Stalevo (CD/LD +comptan)	26.67	13.04	34.78	18.64
MAOB inhibitors				
Rasagilene (azilect)	26.67	17.39	5.56	10.17
Selegilene	6.67	13.04	34.78	18.64
Trihexyphendyl	3.33	0.00	0.00	0.00
Clonazepam	3.33	0.00	0.00	0.00
No PD medications	3.33	4.35	0.00	1.69
1 PD medications	23.30	13.04	41.67	30.51
2 PD medications	56.52	39.13	27.78	32.20
>2 PD medications	30.00	39.13	30.56	33.90

Table 17: Non-Parkinson's Disease Medications Galveston and Houston (%)

Medications	Galveston	Houston 1-23	Houston 24-59	Houston 1-59
Anti-hypertensive	26.67	8.7	11.11	10.17
Anti-hyperlipidemia	10.0	13.04	27.78	22.03
Anticoagulants	6.67	0	8.33	5.08
Oral diabetes	0	4.35	8.33	11.11
Insulin	3.33	0.00	0.00	0.00
Respiratory meds	3.33	4.35	0	1.69
Urinary/prostate medications	3.33	4.35	2.77	3.39
Thyroid meds	0.00	0.00	8.33	5.08
Anti-GERD	3.33	0.00	5.56	3.39
Anemia meds	6.67	0.00	5.56	3.39
Antidepressants	13.33	4.35	8.33	11.11
Anti-anxiety	3.33	0.00	8.33	5.08
Antipsychotics	13.33	0.00	5.56	3.39
Stimulants	0.00	0.00	2.77	1.69
Sleeping pills	0.00	0.00	2.77	1.69
Analgesics/antispasmodics	0.00	0.00	5.56	3.39

RELIABILITY OF DATA

Test-retest reliability data was collected by comparing the scores of 5 Galveston participants, on timed 360 degree turns to both sides, 5 step tests, side stepping in both directions, backward walking, Gait and Balance Scale (GABS) total score, and Unified Parkinson's Disease Rating Scale (UPDRS) total score, both ON & OFF PD medications and measured 2 days to one week apart. Table 18 summarizes all reliability data. All intra class correlations (ICC) for test-retest reliability were greater than 0.893 (range 0.893-0.967). Inter-rater reliability data was gathered from the first 15 subjects both in Houston and Galveston. A physical therapist with expertise in Parkinson's disease and a trained research coordinator who was not a physical therapist, simultaneously rated scores on timed 360 degree turns and 5 step tests, sideways walking, backward walking, GABS, and UPDRS. Additionally scores on the UPDRS were compared between a physical therapist experienced in PD and the neurologist at the VA who simultaneously evaluated 3 participants. All inter-rater reliability ICC scores ranged from 0.968-0.998 for the timed tests and from 0.893 -0.949 for the GABS and the UPDRS total score.

Table 18: Reliability Data (Intra class Correlation Coefficient)

Measure	Inter-rater Reliability (N=15)	Test-retest Reliability (N=5)
360 degree left	0.968	0.961
360 degree right	0.970	0.963
5 step	0.997	0.967
Side step left	0.998	0.967
Side step right	0.997	0.966
Backward walk	0.985	0.967
GABS total score	0.942	0.949
UPDRS total score	0.893	0.875

SPECIFIC AIM 1

This specific aim was to determine which clinical measures of balance and gait correlated with the UPDRS total score and the UPDRS motor section score both ON & OFF PD medications.

Hypothesis 1: There will be a positive relationship (Spearman $r \geq 0.7$) between the 5 step test, timed 360 degree turns, Gait and Balance Scale (GABS) and PIGD (postural instability gait dysfunction) index with the *total score* of the Unified Parkinson's Disability Rating Scale (UPDRS) both ON & OFF PD medications.

Table 19 summarizes the means, ranges, and standard deviations for each of the balance measures and the UPDRS. The mean scores for all balance measures were better ON medications than OFF medications. Additionally the variability of the balance measures decreased in the ON medications state. The high maximum scores for turning in both directions reflect the high incidence of freezing of gait associated with turning, which was expected in our cohort, recruited for falls, freezing of gait and postural instability, and gait dysfunction. It should be noted that the ABC was only measured once, specifically, immediately after the ingestion of PD medications.

Table 20a summarizes the correlations between the PD balance measures and the UPDRS total score both ON & OFF PD medications. There was a significant relationship between the PIGD index OFF medications and the UPDRS total score OFF medications ($r = 0.710$, 95% CI 0.584-0.802). This was the only correlation between the balance measures and the UPDRS that reached significance OFF medications. None of the Spearman's rho correlations between the balance measures and the UPDRS total score were greater than 0.7 ON medications. In order to relate the Spearman's correlations to a known distribution, in this case the normal distribution, we used a one sided Fisher's Z transformation, using the null hypothesis that $r \leq 0.5$ and $\alpha = 0.05$. The lowest

Spearman's rho correlation that was significant ($Z > 1.96$ and therefore Spearman's rho > 0.5) was 0.647. None of the clinical balance measures were significantly correlated with the UPDRS total score ON medications (table 20a). Table 20b shows the correlations between balance measures. All balance measures OFF medications were significantly related to their corresponding balance measures ON medications, ranging from a low correlation of 0.725 (95% CI 0.604 -0.813) for turning 360 degrees to the right, to a high of 0.862 (95% CI 0.794 - 0.908) for the GABS. The correlation between the UPDRS ON & OFF PD medications was also significant ($r = 0.785$, 95% CI 0.686-0.855). Additionally turning 360 degrees to the right was related to turning 360 degrees to the left. OFF medications, turning to the left was associated with turning right ($r = 0.860$, 95% CI 0.792-0.907). ON medications turning to the left was associated with turning right ($r = 0.939$, 95% CI 0.908-0.960). There were also significant relationships between the both the GABS and five step test with turning 360 degrees (Table 20b). The associations between balance measures will be discussed further under specific aim 2.

An additional analysis was done to determine whether any of the balance measures, including the self-rated ABC scale, predicted variability in UPDRS scores both ON & OFF PD medications. A stepwise linear regression was done with the UPDRS OFF medications as the dependent variable. The PIGD index OFF medications and the ABC scale predicted 44.4% of the variability in UPDRS scores in the OFF medications state (Table 23). A second stepwise linear regression with UPDRS ON medications as the dependent variable showed that the GABS ON and PIGD index ON medications predicted 35.8% of the variability in UPDRS scores ON medications (Table 24).

Table 19: Descriptive Statistics Balance Measures and UPDRS All Sites

	N	Minimum	Maximum	Mean	Std. Deviation
GABS off	88	5.00	64.00	29.72	15.10
GABS on	87	0.00	63.00	21.57	12.91
Five step off (s)	83	7.45	48.26	14.66	6.65
Five step on (s)	83	6.30	30.45	11.52	3.66
Turn left off (s)	84	2.00	105.59	6.86	11.37
Turn left on (s)	83	1.98	53.44	4.80	5.76
Turn right off (s)	85	2.13	114.85	7.36	12.39
Turn right on (s)	84	1.86	112.39	5.50	11.98
PIGD off	88	2.00	17.00	6.83	3.21
PIGD on	88	1.00	13.00	5.32	2.79
ABC	87	14.38	98.13	67.64	21.14
UPDRS off	89	15.00	94.00	44.38	16.80
UPDRS on	87	11.00	59.00	33.43	13.34
UPDRS M off	89	6.00	66.00	27.33	11.66
UPDRS M on	87	4.00	37.00	18.62	8.76

GABS – Gait and balance scale
 UPDRS – Unified Parkinson’s disease rating scale
 UPDRS M Unified Parkinson’s disease rating scale motor section
 PIGD – Parkinson’s instability gait dysfunction index
 ABC –Activities specific balance scale

Table 20a: Correlations of Balance Tests with the UPDRS Total Score

	GABS off	GABS on	five step off	five step on	turn left off	turn left on	turn right off	turn right on	PIGD off	PIGD on	UPDRS off	UPDRS On
GABS off	1.000											
GABS on	0.862	1.000										
five step off	0.435	0.441	1.000									
five step on	0.374	0.461	0.751	1.000								
turn left off	0.658	0.564	0.700	0.445	1.000							
turn left on	0.537	0.630	0.633	0.619	0.762	1.000						
turn right off	0.692	0.555	0.643	0.433	0.860	0.694	1.000					
turn right on	0.560	0.644	0.650	0.644	0.749	0.939	0.725	1.000				
PIGD off	0.740	0.633	0.264	0.172	0.555	0.344	0.553	.0379	1.000			
PIGD on	0.605	0.656	0.236	0.167	0.476	0.441	0.443	.0459	0.794	1.000		
UPDRS off	0.632	0.580	0.258	0.179	0.409	0.229	0.416	0.266	0.710	0.620	1.000	
UPDRS On	0.553	0.621	0.182	0.217	0.293	0.318	0.342	0.365	0.508	0.585	0.785	1.000

GABS – Gait and balance scale
 PIGD – Postural Instability Gait Dysfunction Index
 UPDRS – Unified Parkinson’s disease rating scale
Bold- significant correlation p<.05 with Fisher Z transformation

The PIGD index OFF medications was the only balance measure that correlated significantly with the UPDRS total score OFF medications

Table 20b: Significant Correlations between Balance Measures

Variables	Spearman's Rho	Fisher's Z	P	95% confidence interval
GABS off & GABS on	0.862	6.724	0.000	0.794-0.908
GABS off & turn left off	0.658	2.146	0.032	0.516-0.765
GABS off & turn right off	0.692	2.705	0.007	0.560-0.789
GABS off & PIGD off	0.740	3.588	0.000	0.624-0.824
GABS on & PIGD on	0.656	2.115	0.034	0.513-0.763
5 step off & 5 step on	0.751	3.810	0.000	0.639-0.831
5 step off & turn left off	0.700	2.844	0.004	0.571-0.795
5 step off & turn right on	0.650	2.021	0.041	0.506-0.759
Turn left off & turn left on	0.762	4.040	0.000	0.684-0.839
Turn left off & turn right off	0.860	6.655	0.000	0.792-0.907
Turn left off & turn right on	0.749	3.769	0.000	0.637-0.830
Turn left on & turn right off	0.694	2.740	0.006	0.563-0.791
Turn left on & turn right on	0.939	10.566	0.000	0.908-0.960
Turn right off & turn right on	0.725	3.299	0.001	0.604-0.813
PIGD off & PIGD on	0.794	4.766	0.000	0.694-0.859
PIGD off & UPDRS off	0.710	3.022	0.003	0.584-0.802
UPDRS off & UPDRS on	0.785	4.552	0.000	0.686-0.855

GABS – gait and balance scale

PIGD – postural instability gait dysfunction index

UPDRS – Unified Parkinson's disease rating scale

Bold – significant $p < 0.05$ with Fisher's Z transformation

Hypothesis 2 : There will be a positive relationship (Spearman $r \geq 0.7$) between the 5 step test, 360 degree turns, Gait and Balance Scale (GABS) and Postural Instability Gait Dysfunction (PIGD) Index and the *motor section* of the UPDRS, both ON & OFF PD medications.

The descriptive data for the balance parameters and the UPDRS motor section have been presented previously and the reader is referred to Table 19 for their review. None of the balance measure correlations with the UPDRS motor section reached 0.7, both ON & OFF PD medications. Again assuming a null hypothesis of $r \leq 0.50$ and $\alpha = 0.05$, we applied a one sided Fisher's Z transformation to change the Spearman's rho

distribution to the normal distribution. The lowest Spearman's rho correlation that was significant ($Z > 1.96$ and thus the Spearman's rho correlation was significantly greater than 0.5) was 0.647 with 83 subjects. None of the Spearman's rho correlations between the balance measures and the UPDRS motor section scores were greater than 0.7. None of the balance measures correlated significantly with the motor section of the UPDRS in either medications state. Table 21 summarizes these correlations.

Hypothesis 3: There will be a negative relationship (Spearman's rho < 0.7) between GAITRite and over ground measures of velocity, cadence, and stride length, walking forward, fast forward, and backward with the *total score* of the UPDRS, both ON & OFF PD medications.

Instrumented gait was measured walking forward on the GAITRite 5 meter carpet (Cir Corporation, Havertown PA). Different software versions were used at the VA and Galveston sites. Galveston started testing instrumented walking with the GAITRite software version 3.6, upgraded to software version 3.8 and finally graduated to software version 3.9. All data from Galveston was migrated to GAITRite version 3.9 for analysis using a single data base. The Houston site started testing instrumented walking with GAIT Rite software version 3.3 (Cir Corporation, Havertown PA), upgraded to GAITRite software version 3.8 and ultimately to GAITRite software version 3.9. Unfortunately the data from GAITRite software version 3.3 could not be migrated to GAITRite software version 3.9, however all data from GAITRite software version 3.8 was migrated to GAITRite software version 3.9 for analysis. Therefore we divided the Houston subjects into 2 groups, the first VA group 1 did their instrumented gait training on GAITRite software version 3.3 which could not be migrated to version 3.9, and VA group 2 who did their instrumented walking training on the GAITRite software version 3.8 or 3.9 which was migrated to GAITRite software version 3.9 for analysis. All

analyses of the instrumented gait data was performed separately for Galveston and the two VA sites. An additional analysis was done combining the Galveston and VA2 groups since all their instrumented walking evaluations were analyzed by the GAITRite software version 3.9.

Table 21a: Correlations of Balance Measures with UPDRS Motor Score

	GABS off	GABS on	Five step off	Five step on	Turn left off	Turn left on	Turn right off	Turn right on	PIGD off	PIGD on	UPDRS M off	UPDRS M On
GABS off	1.000											
GABS on	0.862	1.000										
five step off	0.435	0.441	1.000									
five step on	0.374	0.461	0.751	1.000								
turn left off	0.658	0.564	0.700	0.445	1.000							
turn left on	0.537	0.630	0.633	0.619	0.762	1.000						
turn right off	0.692	0.555	0.643	0.433	0.860	0.694	1.000					
turn right on	0.560	0.644	0.650	0.644	0.749	0.939	0.725	1.000				
PIGD off	0.740	0.633	0.264	0.172	0.555	0.344	0.553	0.379	1.000			
PIGD on	0.605	0.656	0.236	0.167	0.476	0.441	0.443	0.459	0.794	1.000		
UPDRS M off	0.574	0.552	0.293	0.177	0.445	0.272	0.419	0.298	0.616	0.592	1.000	
UPDRS M on	0.491	0.555	0.210	0.164	0.340	0.315	0.354	0.346	0.532	0.592	0.797	1.000

GABS –gait and balance scale
 PIGD – postural instability gait dysfunction index
 ABC – activities specific balance confidence scale
 UPDRS M– Unified Parkinson’s Disease Rating Scale motor section
Bold – Significant p<.05 with Fisher Z transformation

There were no balance measures that were significantly related to the UPDRS motor section both ON & OFF PD medications

Table 21b: Significant Correlations between Balance Measures & UPDRS Motor Score (excluding those already presented in Table 20b)

Variables	Spearman’s Rho	Fisher’s Z	P	95% confidence interval
UPDRS motor off & UPDRS motor on	0.797	4.839	0.000	0.702-0.864

UPDRS - Unified Parkinson's Disease Rating Scale

Table 22: Regression Analysis for Balance Measures and UPDRS OFF Medications

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.640 ^a	0.410	0.402	13.232
2	0.677 ^b	0.458	0.444	12.757

a. Predictors: (Constant), PIGD off

b. Predictors: (Constant), PIGD off, ABC

ANOVA^c

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	9230.968	1	9230.968	52.720	0.000 ^a
	Residual	13307.186	76	175.095		
	Total	22538.154	77			
2	Regression	10332.287	2	5166.144	31.744	0.000 ^b
	Residual	12205.867	75	162.745		
	Total	22538.154	77			

a. Predictors: (Constant), PIGD off

b. Predictors: (Constant), PIGD off, ABC

c. Dependent variable: UPDRS off medications

Table 23: Regression Analysis for Balance Measures and UPDRS ON Medications

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.578 ^a	0.334	0.326	10.689
2	0.613 ^b	0.375	0.358	10.426

a. Predictors: (Constant), GABS on

b. Predictors: (Constant), GABS on, PIGD Index on

ANOVA^c

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4305.071	1	4305.071	37.683	0.000 ^a
	Residual	8568.383	75	114.245		
	Total	12873.455	76			
2	Regression	4830.283	2	2415.141	22.220	0.000 ^b
	Residual	8043.172	74	108.692		
	Total	12873.455	76			

a. Predictors: (Constant), GABS on

b. Predictors: (Constant), GABS on, PIGD Index on

c. Dependent Variable: UPDRS on

Walking Forward at Usual Speed:

Velocity:

Tables 24a-d summarize the descriptive statistics for velocity, cadence, stride length and UPDRS total and motor section scores for all groups, ON & OFF PD medications, and walking on the instrumented GAITRite software version 3.9 and over ground. In all cases velocity and stride length increased significantly while cadence remained relatively unchanged moving from OFF to ON PD medications (Tables 24e-h). Velocity was higher walking on the GAITRite than walking over ground both ON & OFF PD medications (Tables 24e-h). Velocity was highest at the VA group 2 and lowest at the VA group 1 under the following 4 conditions - 1) OFF medications on the GAITRite, 2) ON medications on the GAITRite, 3) OFF medications over ground and 4) ON medications over ground. The range between sites for velocity OFF medications on the GAITRite was 75.79 ± 30.76 to 93.43 ± 25.19 centimeters/second. The range between sites for velocity OFF medications over ground was 67.05 ± 28.83 to 85.29 ± 23.96 centimeters/second. The range between sites for velocity ON medications on the GAITRite was 90.92 ± 21.35 to 108.91 ± 23.23 centimeters/second. Finally the range between sites for velocity ON medications over ground was 80.94 ± 15.49 to 94.66 ± 25.4 centimeters/second.

Cadence

Cadence remained relatively stable moving from OFF medications to ON medications at all sites, regardless of walking surface (Tables 24a-h). The range between sites for cadence OFF medications and on the GAITRite was 103.49 ± 18.41 in Galveston to 118.54 ± 33.98 steps/minute at the VA Group 1. The range between sites for cadence OFF medications over ground was 96.0 ± 16.99 steps/minute at the VA Group 1 to 104.88 ± 13.13 steps/minute at the VA Group 2. The range between sites for cadence ON

medications on the GAITRite was 110.03 ± 14.55 steps/minute at the VA Group 2 to 117.15 ± 28.20 steps/minute at the VA Group 1. Finally the range between sites for cadence ON medications over ground was 93.88 ± 21.89 steps/minute in Galveston to 104.45 ± 17.09 steps/minute at the VA Group 2. The range between scores was much tighter for cadence than velocity. It should be noted that cadence walking on the GAITRite ON medications was within decimal points of 110 steps/minute at all sites with the exception of the VA Group 1.

Stride Length

On the GAITRite stride length was highest at the VA group 2 and lowest at the VA group 1 both ON & OFF PD medications (Table 24 a-d). The range between sites for stride length on the GAITRite was 78.74 ± 24.64 to 99.64 ± 25.13 centimeters OFF medications. Over ground and OFF medications, the range between sites for stride length was 81.69 ± 29.16 to 100.29 ± 34.5 centimeters. Over ground stride length was highest in Galveston and lowest in VA group 1 both ON & OFF PD medications. Stride length between sites ranged from 96.7 ± 17.66 to 113.57 ± 26.57 centimeters ON medications on the GAITRite. Over ground and ON medications, the range between sites for stride length was 94.12 ± 23.54 to 109.84 centimeters. (Tables 24a-d). The reader should also note how close stride length is on the GAITRite and over ground in both medications states (Tables 24a-d).

Table 24a: Descriptive Statistics Galveston Walking Forward Usual Speed

	N	Minimum	Maximum	Mean	Std. Deviation
GR velocity OFF (centimeters/second)	30	12.70	112.90	76.69	26.66
OG velocity OFF (centimeters/second)	30	25.46	137.50	77.11	28.39
GR velocity ON (centimeters/second)	30	56.70	131.60	98.49	20.81
OG velocity ON (centimeters/second)	28	47.29	120.09	85.25	17.94
GR cadence OFF (steps/minute)	30	62.40	165.65	103.49	18.41
OG cadence OFF (steps/minute)	30	48.00	129.76	96.67	16.58
GR cadence ON (steps/minute)	30	93.70	187.40	110.16	17.06
OG cadence ON (steps/minute)	28	40.00	129.23	93.88	21.89
GR stride length OFF (centimeters)	30	48.33	177.60	93.83	29.01
OG stride length OFF (centimeters)	30	42.30	183.33	100.29	34.50
GR stride length ON (centimeters)	30	69.69	144.54	109.05	21.51
OG stride length ON (centimeters)	28	57.89	183.33	109.84	28.53
UPDRS OFF	30	17.00	67.00	37.33	14.48
UPDRS ON	28	11.00	57.00	27.07	14.30
UPDRSM OFF	30	9.00	42.00	21.87	9.85
UPDRSM ON	28	4.00	36.00	13.96	9.17

GR- GAITRite

OG- over ground

UPDRS – Unified Parkinson’s disease rating scale

UPDRSM – Unified Parkinson’s disease rating scale motor section

Table 24b: Descriptive Statistics VA Group 1 Walking Forward Usual Speed

	N	Minimum	Maximum	Mean	Std. Deviation
GR velocity OFF (centimeters/second)	21	20.10	124.30	75.79	30.76
OG velocity OFF (centimeters/second)	22	19.90	115.70	67.05	25.85
GR velocity ON (centimeters/second)	23	51.80	124.60	90.92	21.35
OG velocity ON (centimeters/second)	22	57.10	108.80	80.94	15.49
GR cadence OFF (steps/minute)	22	71.50	202.55	118.54	33.98
OG cadence OFF (steps/minute)	23	35.79	121.56	96.00	16.99
GR cadence ON (steps/minute)	23	86.10	188.75	117.15	28.20
OG cadence ON (steps/minute)	23	78.60	132.49	102.12	14.92
GR stride length OFF (centimeters)	22	29.65	130.64	78.74	24.64
OG stride length OFF (centimeters)	23	31.25	142.86	81.69	29.16
GR stride length ON (centimeters)	23	57.67	132.33	96.70	17.66
OG stride length ON (centimeters)	23	62.50	142.85	94.12	21.54
UPDRS OFF	23	31.00	76.00	52.91	12.91
UPDRS ON	23	27.00	56.00	41.48	9.59
UPDRS M OFF	23	19.00	49.00	33.91	7.74
UPDRS M ON	23	14.00	37.00	23.43	6.02

GR- GAITRite

OG- over ground

UPDRS – Unified Parkinson’s disease rating scale

UPDRSM- Unified Parkinson’s disease rating scale – motor scale

Table 24c: Descriptive Statistics VA Group 2 Walking Forward Usual Speed

	N	Minimum	Maximum	Mean	Std. Deviation
GR velocity OFF (centimeters/second)	36	34.90	172.00	93.43	25.19
OG velocity OFF (centimeters/second)	36	26.60	132.45	85.29	23.96
GR velocity ON (centimeters/second)	36	36.00	155.70	108.91	23.23
OG velocity ON (centimeters/second)	36	19.80	142.90	94.66	25.40
GR cadence OFF (steps/minute)	36	11.20	159.80	108.05	21.85
OG cadence OFF (steps/minute)	36	78.26	136.67	104.88	13.13
GR cadence ON (steps/minute)	36	75.80	147.70	110.33	14.55
OG cadence ON (steps/minute)	35	65.80	146.34	104.45	17.09
GR stride length OFF (centimeters)	36	43.21	149.41	99.64	25.13
OG stride length OFF (centimeters)	36	33.33	142.86	95.55	22.75
GR stride length ON (centimeters)	36	43.21	160.12	113.57	26.57
OG stride length ON (centimeters)	36	35.71	142.86	107.09	23.31
UPDRS OFF	36	15.00	94.00	45.08	18.09
UPDRS ON	36	13.00	59.00	33.08	11.89
UPDRS M OFF	36	6.00	66.00	27.66	13.02
UPDRS M ON	36	4.00	36.00	19.16	8.24

GR-GAITRite

OG- over ground

UPDRS – Unified Parkinson’s disease rating scale

UPDRSM- Unified Parkinson’s disease rating scale motor section

Table 24d: Descriptive Statistics Galveston & VA Group 2 Walking Forward Usual Speed & UPDRS Total Score and Motor Score

	N	Minimum	Maximum	Mean	Std. Deviation
GR velocity OFF (centimeters/second)	66	12.70	172.00	85.82	27.01
OG velocity OFF (centimeters/second)	66	25.46	137.50	81.58	26.19
GR velocity ON (centimeters/second)	66	36.00	155.70	104.17	22.61
OG velocity ON (centimeters/second)	64	19.80	142.90	90.55	22.77
GR cadence OFF (steps/minute)	66	11.20	165.65	105.98	20.34
OG cadence OFF (steps/minute)	66	48.00	136.67	101.15	15.25
GR cadence ON (steps/minute)	66	75.80	187.40	110.25	15.62
OG cadence ON (steps/minute)	63	40.00	146.34	100.32	20.08
GR stride length OFF (centimeters)	66	43.21	177.60	97.89	26.38
OG stride length OFF (centimeters)	66	42.30	183.33	98.88	27.44
GR stride length ON (centimeters)	66	43.21	160.12	112.20	24.02
OG stride length ON (centimeters)	64	35.71	183.33	109.25	24.45
UPDRS OFF	66	15.00	94.00	41.56	16.88
UPDRS ON	64	11.00	59.00	30.45	13.24
UPDRSM OFF	66	6.00	66.00	25.03	11.96
UPDRSM ON	64	4.00	36.00	16.89	8.97

GR-GAITRite

OG- over ground

UPDRS – Unified Parkinson’s disease rating scale

UPDRSM- Unified Parkinson’s disease rating scale motor section

Table 24e: Galveston Paired T-Tests Gait Parameters Walking ON & OFF PD Medications

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Gal GR vel OFF - Gal GR vel ON	-21.80	25.09	4.58	-31.17	-12.43	-4.758	29	0.000
Pair 2	Gal OG vel OFF - Gal OG vel ON	-9.13	20.88	3.95	-17.23	-1.04	-2.314	27	0.028
Pair 3	Gal GR cad OFF - GAL GR cad ON	-6.67	22.40	4.09	-15.04	1.70	-1.631	29	0.114
Pair 4	Gal OG cad OFF - Gal OG cad ON	3.17	21.95	4.15	-5.34	11.68	0.764	27	0.452
Pair 5	Gal GR SL OFF - Gal GR SL ON	-15.22	23.11	4.22	-23.84	-6.59	-3.606	29	0.001
Pair 6	Gal OG SL OFF - Gal OG SL ON	-11.74	19.57	3.70	-19.33	-4.15	-3.175	27	0.004

Gal – Galveston
 GR – GAITRite
 OG – over ground
 Cad – cadence
 SL – stride length

Bold – significant p<0.05

Table 24f: VA Group 1 Paired T-Tests Gait Parameters Walking ON & OFF PD Medications

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	VA1 GR vel OFF - VA1 GR vel ON	-16.09	20.87	4.55	-25.60	-6.60	-3.534	20	0.002
Pair 2	VA1 OG vel OFF - VA1 OG vel ON	-13.88	19.42	4.14	-22.49	-5.27	-3.352	21	0.003
Pair 3	VA1 GR cad OFF - VA1 GR cad ON	0.68	27.06	5.77	-11.32	12.68	0.118	21	0.907
Pair 4	VA1 OG cad OFF - VA1 OG cad ON	-6.12	18.29	3.81	-14.03	1.79	-1.604	22	0.123
Pair 5	VA1 GR SL OFF - VA1 GR SL ON	-16.72	17.18	3.66	-24.34	-9.10	-4.565	21	0.000
Pair 6	VA1 OG SL OFF - VA1 OG SL ON	-12.43	20.60	4.29	-21.34	-3.53	-2.895	22	0.008

VA1 – VA Group 1
 GR – GAITRite
 OG – over ground
 Vel - velocity
 Cad – cadence
 SL – stride length

Bold – significant p<0.05

Table 24g: VA Group 2 Paired T-Tests Gait Parameters Walking ON& OFF PD Medications

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	VA2 vel GR OFF - VA2 vel GR ON	-15.48	18.95	3.16	-21.89	-9.07	-4.900	35	0.000
Pair 2	VA2 vel OG OFF - VA2 vel OG ON	-9.37	13.43	2.24	-13.92	-4.83	-4.186	35	0.000
Pair 3	VA2 GR cad OFF - V2 GR cad ON	-2.27	29.35	4.89	-12.20	7.66	-0.464	35	0.645
Pair 4	VA2 OG cad OFF - VA2 OG cad ON	-0.18	21.56	3.64	-7.59	7.22	-0.050	34	0.961
Pair 5	VA2 GR SL OFF - VA2 GR SL ON	-13.92	28.71	4.79	-23.64	-4.21	-2.909	35	0.006
Pair 6	VA2 OG SL OFF - VA2 OG SL ON	-11.03	28.40	4.73	-20.64	-1.42	-2.331	35	0.026

VA2 –VA Group 2
 GR – GAITRite
 OG – over ground
 Vel – velocity
 Cad – cadence
 SL – stride length

Bold – significant p<0.05

Table 24h: Galveston VA Group 2 Paired T-Tests Walking ON & OFF PD Medications

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	GV2 GR vel OFF - GV2 GR vel ON	-18.35	22.00	2.71	-23.76	-12.94	-6.774	65	0.000
Pair 2	GV2 OG vel OFF - GV2 OG vel ON	-9.27	16.94	2.12	-13.50	-5.03	-4.375	63	0.000
Pair 3	GV2 GR Cad OFF - GV2 GR Cad ON	-4.27	26.32	3.24	-10.74	2.02	-1.318	65	0.192
Pair 4	GV2 OG Cad OFF - GV2 OG Cad ON	0.74	21.39	2.70	-4.64	6.13	0.276	62	0.784
Pair 5	GV2 GR SL OFF - GV2 GR SL ON	-14.32	26.09	3.21	-20.73	-7.90	-4.457	65	0.000
Pair 6	GV2 OG SL OFF - GV2 OG SL ON	-11.37	18.56	2.32	-16.01	-6.74	-4.901	63	0.000

GV2 –Galveston VA Group 2 combined group
 OG – over ground
 Vel – velocity
 Cad – cadence
 SL – stride length

Bold – significant p<0.05

Correlations between UPDRS & UPDRS Motor Scores

Both the UPDRS and UPDRS motor scores improved, specifically decreased from the OFF to the ON PD medications state. Lower scores indicate less disease severity.

Correlations between Gait Parameters and the UPDRS

Tables 25a-29a summarize correlations between gait parameters (velocity, cadence and stride length) with the UPDRS walking forward at a usual speed in both medications states on the GAITRite and over ground, for Galveston, VA Group 1, VA Group 2 and Galveston VA Group 2 respectively. None of the Spearman's rho correlation coefficients between the gait parameters and the UPDRS total score were greater than 0.7, both ON & OFF PD medications, and walking on the GAITRite and over ground. Spearman's rho correlations were transformed using a one sided Fisher's Z calculation at all sites to normalize the distributions. We assumed a null hypothesis of $r \leq 0.5$, and an alpha of 0.05, when performing the one sided Fisher's Z transformation. In Galveston for 30 subjects, the lowest Spearman's rho correlation coefficient that was significant ($Z > 1.96$ thus the Spearman's rho correlation was significantly greater than 0.5) was 0.729. At the VA Group 1 for 23 clients, the lowest Spearman's rho correlation coefficient that was significant ($Z > 1.96$ thus the Spearman's rho correlation was significantly greater than 0.5) was 0.756. At the VA Group 2 with 36 participants, the lowest Spearman's rho correlation coefficient that was significant ($Z > 1.96$ thus Spearman's rho was significantly greater than 0.5) was 0.712. Finally in the Galveston -VA2 group with 66 individuals, the lowest Spearman's rho correlation coefficient that was significant ($Z > 1.96$ and thus the Spearman's rho greater than 0.5) was 0.662. At all sites there were no significant relationships between any of the gait parameters and the UPDRS, both on the GAITRite and over ground, and ON or OFF PD medications.

Correlations between Gait Parameters

Several significant relationships emerged between gait parameters (Tables 25b-28b). Over ground, velocity correlated significantly ON & OFF PD medications at the VA Group 2 ($r = 0.828$, 95% confidence interval 0.684 - 0.910), and in the combined group ($r=0.771$, 95% confidence interval 0.648 - 0.854). When walking over ground, stride length was significantly associated ON & OFF PD medications in Galveston ($r = 0.788$, 95% confidence interval 0.588 - 0.897), and in the combined group ($r = 0.688$, 95% confidence interval 0.533 - 0.798). There were several significant relationships between stride length and gait velocity, both ON & OFF PD medications, as well as walking on both surfaces. First over ground in the OFF medications state, there was a strong correlation between velocity and stride length at the VA2 ($r = 0.784$, 95% confidence interval 0.611 -0.885). Similarly OFF medications, but this time on the GAITRite, the association between stride length and velocity was excellent ($r = 0.823$, 95% confidence interval 0.678 - 0.906) for the individuals in VA group 2. Finally ON medications and still on the GAITRite, there was a significant relationship between stride length and velocity in Galveston ($r=0.893$, 95% confidence interval 0.780 - 0.949). Moreover there were additional correlations between walking on the GAITRite and walking over ground, both ON & OFF PD medications. First OFF medications there was an excellent correlation for velocity on the GAITRite and over ground at the VA group 1 ($r = 0.848$, 95% confidence interval 0.670 - 0.933). Still OFF medications, there was a strong association for stride length on the GAITRite and over ground for individuals at the VA group 2 ($r = 0.827$, 95% confidence interval 0.682 - 0.909). Finally in Galveston in the OFF medications state, there was a strong correlation between stride length on the GAITRite and velocity over ground ($r = 0.735$, 95% confidence interval 0.499 - 0.869).

Walking Forward at a Fast Speed

Fast gait velocity was measured both over ground and on the GAITRite software version 3.9 (Cir Corporation, Havertown PA). Unfortunately counting the number of steps to walk the 5 meters over ground was not part of the research protocol, hence cadence and stride length could not be calculated for fast over ground walks.

Table 25a: Spearman’s Correlations Galveston Gait Parameters Walking Forward Usual Speed & UPDRS Total Score

	GR vel OFF	OG vel OFF	GR vel ON	OG vel ON	GR cad OFF	OG cad OFF	GR cad ON	OG cad ON	GR SL OFF	OG SL OFF	GR SL ON	OG SL ON	UPDRS OFF	UPDRS ON
GR vel OFF	1.000													
OG vel OFF	0.374	1.000												
GR vel ON	0.515	0.395	1.000											
OG vel ON	0.365	0.680	0.527	1.000										
GR cad OFF	0.612	0.251	0.255	0.143	1.000									
OG cad OFF	0.228	0.349	0.213	0.075	0.390	1.000								
GR cad ON	0.438	0.008	0.413	0.205	0.488	0.193	1.000							
OG cad ON	0.279	0.272	0.065	0.492	0.253	0.241	0.089	1.000						
GR SL OFF	0.673	0.424	0.644	0.561	0.288	0.164	0.219	0.221	1.000					
OG SL OFF	0.524	0.735	0.610	0.472	0.213	0.117	0.196	0.108	0.572	1.000				
GR SL ON	0.402	0.474	0.893	0.722	0.046	0.160	0.063	0.106	0.660	0.569	1.000			
OG SL ON	0.343	0.413	0.645	0.473	0.079	0.001	0.010	0.334	0.497	0.788	0.678	1.000		
UPDRS OFF	-0.204	-0.151	-0.155	-0.127	-0.001	-0.245	-0.067	-0.162	-0.005	-0.007	-0.082	-0.044	1.000	
UPDRS ON	-0.266	-0.068	-0.050	-0.141	-0.110	-0.175	-0.003	-0.081	-0.233	-0.146	-0.017	-0.140	-0.824	1.000

GR – GAITRite
 OG – over ground
 Vel - velocity
 cad – cadence
 SL – stride length

UPDRS – Unified Parkinson’s disease rating scale

Bold- significant correlation p<.05 with Fisher’s Z transformation

None of the gait parameters walking forward were significantly correlated with the UPDRS total score ON & OFF PD medications

Table 25b: Significant Correlations between Gait Parameters Galveston Walking Forward Usual Speed

Variable	Spearman's Rho	Fisher Z	P	95% confidence interval
OG vel off & OG SL off	0.735	1.951	0.05	0.499-0.869
GR vel on & GR SL on	0.893	4.436	0.00	0.780-0.949
OG SL off & OG SL on	0.788	2.584	0.01	0.588-0.897
UPDRS off & UPDRS on	0.824	3.099	0.002	0.652-0.915

GR – GAITRite
 OG - over ground
 Vel – velocity
 SL – stride length

Table 26a: Spearman's Rho Correlations VA Group 1 Gait Parameters Walking Forward Usual Speed & UPDRS Total Score

	GR vel OFF	OG vel ON	GR vel ON	OG vel ON	GR cad OFF	OG cad OFF	GR cad ON	OG cad ON	GR SL OFF	OG SL OFF	GR SL ON	OG SL ON	UPDRS OFF	UPDRS ON
GR vel OFF	1.000													
OG vel OFF	0.848	1.000												
GR vel ON	0.696	0.682	1.000											
OG vel ON	0.552	0.656	0.563	1.000										
GR cad OFF	0.447	0.441	0.495	0.090	1.000									
OG cad OFF	0.087	0.140	0.011	0.122	0.007	1.000								
GR cad ON	0.304	0.377	0.543	0.313	0.669	0.128	1.000							
OG cad ON	0.266	.355	0.046	0.004	0.054	0.481	0.317	1.000						
GR SL OFF	0.234	0.218	0.111	0.183	0.232	0.388	0.249	0.169	1.000					
OG SL OFF	0.650	0.637	0.643	0.587	0.260	0.074	0.330	0.169	.311	1.000				
GR SL ON	0.049	0.070	0.095	0.181	0.153	0.013	0.301	0.023	0.728	0.299	1.000			
OG SL ON	0.298	0.345	0.217	0.691	0.010	0.084	0.082	0.328	0.126	0.638	0.331	1.000		
UPDRS OFF	-	-	-	-	-	-	-	-	-	-	-	-	1.000	
UPDRS ON	0.241	0.035	0.064	0.208	0.129	0.117	0.012	0.073	0.309	0.129	0.219	0.178	-	1.000
	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0.026	0.034	0.034	0.122	0.075	0.051	0.048	0.042	0.290	0.080	0.199	0.116	0.672	1.000

GR – GAITRite
 OG – over ground
 Vel – velocity
 Cad – cadence
 SL- stride length
 UPDRS –Unified Parkinson's disease rating scale
Bold- significant correlation p<.05

None of the gait parameters walking forward were significantly correlated with the UPDRS total score ON & OFF PD medications

Table 26b: Significant Correlations between Gait Parameters

Variables	Spearman's Rho	Fisher's Z	P	95% confidence intervals
GR vel off & OG vel off	0.848	3.129	0.002	0.670-0.933

GR - GAITRite
 OG - over ground
 Vel - velocity

Table 27a: Spearman's Rho Correlations VA Group 2 Gait Parameters Walking Forward Usual Speed & UPDRS Total Score

	GR vel OFF	OG vel OFF	GR vel ON	OG vel ON	GR cad OFF	OG cad OFF	GR cad ON	OG cad ON	GR SL OFF	OG SL OFF	GR SL ON	OG SL ON	UPDRS OFF	UPDRS ON
GR vel OFF	1.000													
OG vel OFF	0.578	1.000												
GR vel ON	0.676	0.599	1.000											
OG vel ON	0.615	0.828	0.674	1.000										
GR cad OFF	0.292	0.030	0.260	.237	1.000									
OG cad OFF	0.342	0.589	0.519	0.647	0.465	1.000								
GR cad ON	-0.104	-0.012	-0.160	-0.045	-0.247	-0.119	1.000							
OG cad ON	0.250	0.206	0.109	.185	0.048	0.027	0.064	1.000						
GR SL OFF	0.823	0.605	0.606	0.639	0.046	0.188	0.068	0.328	1.000					
OG SL OFF	0.584	0.784	0.480	0.670	0.163	0.182	0.187	0.292	0.827	1.000				
GR SL ON	0.405	0.347	0.549	0.508	0.075	0.108	0.198	0.107	0.503	0.451	1.000			
OG SL ON	-0.073	-0.150	-0.024	-0.221	-0.021	-0.134	-0.158	-0.207	-0.039	-0.125	-0.049	1.000		
UPDRS OFF	-0.421	-0.609	-0.215	-0.415	-0.178	-0.104	-0.254	-0.385	-0.502	-.0590	-0.227	0.062	1.000	
UPDRS ON	-0.366	-0.529	-0.227	-0.434	-0.049	-0.260	-0.230	-0.283	-0.416	-0.442	-0.062	-0.158	0.800	1.000

GR – GAITRite
 OG – over ground
 Vel – velocity
 Cad – cadence
 SL – stride length
 UPDRS – Unified Parkinson's disease rating scale

Bold- significant correlation p<.05 with Fisher's Z transformation

None of the gait parameters walking forward were significantly correlated with the UPDRS total score ON & OFF PD medications

Table 27b: Significant Correlations between Gait Parameters VA2 Walking Forward Usual Speed

Variables	Spearman's Rho	Fisher's Z	P	95% confidence interval
GR vel off & GR SL off	0.823	3.543	0.000	0.678-0.906
OG vel off & OG vel on	0.828	3.578	0.000	0.684-0.910
OG vel off & OG SL off	0.784	2.864	0.004	0.611-0.885
GR SL off & OG SL off	0.827	3.560	0.000	0.682-0.909
UPDRS off & UPDRS on	0.800	3.107	0.002	0.637-0.894

GR – GAITRite
 OG – over ground
 Vel – velocity
 SL – stride length
 UPDRS – Unified Parkinson's disease rating scale

Table 28a: Spearman's Rho Correlations Galveston & VA Group 2 Gait Parameters Walking Forward Usual Speed & UPDRS Total Score

	GR vel OFF	OG vel OFF	GR vel ON	OG vel ON	GR cad OFF	OG cad OFF	GR cad ON	OG cad ON	GR SL OFF	OG SL OFF	GR SL ON	OG SL ON	UPDRS OFF	UPDRS ON
GR vel OFF	1.000													
OG vel OFF	0.518	1.000												
GR vel ON	0.637	0.551	1.000											
OG vel ON	0.580	0.771	0.657	1.000										
GR cad OFF	-0.016	-	-	0.109	1.000									
OG cad OFF	-0.078	-	0.071	0.029	0.481	1.000								
GR cad ON	0.010	0.038	0.082	0.205	0.084	0.071	1.000							
OG cad ON	0.131	0.089	0.149	0.087	0.259	0.203	0.034	1.000						
GR SL OFF	0.079	0.072	0.030	0.152	0.081	0.204	0.230	0.281	1.000					
OG SL OFF	0.001	0.102	0.055	0.168	0.059	0.107	0.221	0.061	0.655	1.000				
GR SL ON	0.071	0.059	0.083	0.147	0.018	0.159	0.131	0.120	0.574	0.470	1.000			
OG SL ON	0.145	0.003	0.053	0.205	0.065	0.078	0.138	0.153	0.589	0.688	0.605	1.000		
UPDRS OFF	-	-	-	-	-	-	-	-	-	-	-	-	1.000	
UPDRS ON	0.061	0.314	0.154	0.127	0.071	0.042	0.093	0.153	0.008	0.135	0.087	0.222	-	1.000
	0.042	0.219	0.101	0.105	0.010	0.119	0.121	0.196	0.021	0.173	0.163	0.171	0.816	-

GR – GAITRite
 OG – over ground
 Vel – velocity
 Cad – cadence
 SL – stride length
 UPDRS – Unified Parkinson's disease rating scale
Bold- significant correlation p<.05 with a Fisher Z transformation

None of the gait parameters walking forward were significantly correlated with the UPDRS total score ON & OFF PD medications

Table 28b: Significant Correlations between Gait Parameters Galveston VA2 Walking Forward Usual Speed

Variables	Spearman's Rho	Fisher's Z	P	95% confidence interval
OG vel off & OG vel on	0.771	3.698	0.000	0.648-0.854
OG SL off & OG SL on	0.688	2.303	0.021	0.533-0.798
UPDRS off & UPDRS on	0.816	4.650	0.000	0.714-0.884

GR – GAITRite
 OG – over ground
 Vel – velocity
 SL – stride length

Table 29a: Descriptive Information Galveston Walking Fast Forward & UPDRS Total & Motor Scores

	N	Minimum	Maximum	Mean	Std. Deviation
GR fast vel OFF (centimeters/second)	29	55.80	218.50	127.80	34.87
OG fast vel OFF (centimeters/second)	30	30.09	189.74	116.39	41.72
GR fast vel ON (centimeters/second)	29	76.40	216.40	144.26	30.97
OG fast vel ON (centimeters/second)	28	65.40	195.72	128.84	34.78
GR fast cad OFF (steps/minute)	29	73.50	213.95	133.47	28.09
GR fast cad ON (steps/minute)	30	74.80	173.20	131.52	18.94
GR fast SLOFF (centimeters)	29	64.63	171.28	114.07	25.82
GR fast SL ON (centimeters)	29	78.30	172.09	128.86	25.36
UPDRS OFF	30	17.00	67.00	37.33	14.48
UPDRS ON	28	11.00	57.00	27.07	14.30
UPDRS M OFF	30	9.00	42.00	21.8	9.85
UPDRS M ON	28	4.00	36.00	13.96	9.17

GR – GAITRite
 OG – over ground
 fvel – fast velocity
 fcad – fast cadence
 fSL – fast stride length
 UPDRS – Unified Parkinson's disease rating scale
 UPDRS - Unified Parkinson's disease rating scale motor section

Table 29b: Descriptive Information VA Group 1 Walking Fast Forward & UPDRS Total & Motor Scores

	N	Minimum	Maximum	Mean	Std. Deviation
GR fvel OFF (centimeters/second)	21	44.80	202.50	119.21	40.54
OG fvel OFF (centimeters/second)	22	37.00	140.40	94.90	30.90
GR fvel ON (centimeters/second)	22	85.10	232.15	136.75	34.87
OG fvel ON (centimeters/second)	22	71.60	164.80	116.28	28.88
GR fcad OFF (steps/minute)	22	95.35	213.95	137.25	23.42
GR fcad ON (steps/minute)	22	111.15	232.75	140.00	25.92
GR fSL OFF (centimeters)	21	45.55	161.09	106.77	26.70
GR fSL ON (centimeters)	22	69.99	162.69	118.15	22.95
UPDRS OFF	23	31.00	76.00	52.91	12.91
UPDRS ON	23	27.00	56.00	41.48	9.59
UPDRS M OFF	23	19.00	49.00	33.91	7.74
UPDRS M ON	23	14.00	37.00	23.43	6.02

GR – GAITRite
 OG – over ground
 fvel – fast velocity
 fcad – fast cadence
 fSL – fast stride length
 UPDRS – Unified Parkinson’s disease rating scale
 UPDRS M - Unified Parkinson’s disease rating scale motor section

Table 29c: Descriptive Information VA Group 2 Walking Fast Forward & UPDRS Total & Motor Scores

	N	Minimum	Maximum	Mean	Std. Deviation
GR fast vel OFF (centimeters/second)	36	67.90	246.10	143.19	38.33
OG fast vel OFF (centimeters/second)	36	38.50	217.40	124.08	34.96
GR fast vel ON (centimeters/second)	36	63.80	219.30	149.44	35.17
OG fast vel ON (centimeters/second)	36	56.40	218.30	135.52	36.04
GR fast cad OFF (steps/minute)	36	112.10	197.10	134.73	16.90
GR fast cad ON (steps/minute)	36	110.60	186.30	132.67	14.73
GR fast SL OFF (centimeters)	36	70.29	181.37	129.08	26.01
GR fast SL ON (centimeters)	36	70.46	195.00	136.30	25.38
UPDRS OFF	36	15.00	94.00	45.08	18.09
UPDRS ON	36	13.00	59.00	33.08	11.89
UPDRS M OFF	36	6.00	66.00	27.67	13.02
UPDRS M ON	36	4.00	36.00	19.17	8.24

GR – GAITRite
 OG – over ground
 fvel – fast velocity
 fcad – fast cadence
 fSL – fast stride length
 UPDRS – Unified Parkinson’s disease rating scale
 UPDRS - Unified Parkinson’s disease rating scale motor section

Table 29d: Descriptive Information Galveston VA Group 2 Walking Fast Forward and UPDRS Total & Motor Scores

	N	Minimum	Maximum	Mean	Std. Deviation
GR fast vel OFF (centimeters/second)	66	55.80	246.10	135.94	37.19
OG fast vel OFF (centimeters/second)	66	30.09	217.40	119.88	38.31
GR fast vel ON (centimeters/second)	66	63.80	219.30	146.60	33.23
OG fast vel ON (centimeters/second)	65	56.40	218.30	131.46	36.27
GR fast cad OFF (steps/minute)	64	77.00	213.95	134.12	21.22
GR fast cad ON (steps/minute)	65	43.03	186.30	132.04	14.96
GR fast SL OFF (centimeters)	65	64.63	181.37	122.38	26.80
GR fast SL ON (centimeters)	65	70.46	195.00	132.98	25.44
UPDRS OFF	66	15.00	94.00	41.56	16.88
UPDRS ON	64	11.00	59.00	30.451	13.24
UPDRS M OFF	66	6.00	66.00	25.03	11.96
UPDRS M ON	64	4.00	36.00	16.89	8.97

GR – GAITRite
 OG – over ground
 Vel - velocity
 cad – cadence
 SL – Stride length
 UPDRS – Unified Parkinson’s disease rating scale
 UPDRS M – Unified Parkinson’s disease rating scale motor section

Table 29e: Paired T-Tests Gait Velocity Walking Fast Forward OFF-ON Medications

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Gal fvel GR OFF - Gal fvel GR ON	-16.47	21.62	4.01	-24.69	-8.24	-4.102	28	0.000
Pair 2	Gal fvel OG OFF - Gal fvel OG ON	-11.79	24.36	4.60	-21.23	-2.34	-2.560	27	0.016
Pair 3	V1 fvel GR OFF - V1 fvel GR ON	-17.42	26.53	5.66	-29.18	-5.65	-3.079	21	0.006
Pair 4	V1 fvel OG OFF - V1 fvel OG ON	-21.46	30.84	6.43	-34.795	-8.12	-3.337	22	0.003
Pair 5	V2 fvel GR OFF - V2 fvel GR ON	-6.12	21.67	3.56	-13.345	1.11	-1.717	36	0.094
Pair 6	V2 fvel OG OFF - V2 fvel OG ON	-10.44	22.22	3.65	-17.85	-3.03	-2.858	36	0.007
Pair 7	GV2 fvel GR OFF- GV2 fvel GR ON	-10.66	22.09	2.72	-16.10	-5.23	-3.922	65	0.000
Pair 8	GV2 fvel OG OFF- GV2 fvel OG ON	-11.02	22.99	2.85	-16.72	-5.32	-3.865	64	0.000

Gal – Galveston
V1 – VA Group 1
V2 – VA Group 2
GV2 – Galveston VA2 combined group
Fvel – fast velocity
Bold – significant p<.05

Velocity

Tables 29a-d summarize the descriptive statistics for fast walking in both medication states, both on the GAITRite and over ground. Table 29e reviews paired t-tests for velocity at all sites walking fast forward, ON & OFF PD medications. Similar to walking at a usual speed, gait velocity was greater walking fast ON PD medications than OFF medications. This difference was statistically significant on the GAITRite at all sites with the exception of the VA Group 2, and over ground was statistically significant at all sites. When participants walked fast, gait velocity was also significantly higher walking on the GAITRite than walking over ground, with the exception of Galveston OFF

medications. We will return to examine the equivalence of measurements on the GAITRite and over ground under specific aim 3. Gait velocity was highest at the VA Group 2 and lowest at the VA Group 1, across both walking surfaces, and both medications states. Gait velocity walking fast forward OFF medications on GAITRite ranged (mean and standard deviation) from a low of 119.21 ± 40.53 centimeters/second at the VA Group 1, to a high of 143.19 ± 38.33 centimeters/second at the VA Group 2. Over ground OFF medications, gait velocity walking fast forward, ranged (mean and standard deviation) from a low of 94.90 ± 30.90 centimeters/second at the VA Group 1, to a high of 124.08 ± 34.96 centimeters/second at the VA Group 2. ON medications and on the GAITRite, gait velocity walking fast forward ranged (mean and standard deviation) from a low of 136.75 ± 34.87 at the VA Group 1, to a high of 149.44 ± 35.17 centimeters/second at the VA Group 2. Finally ON medications and walking over ground fast forward, gait velocity ranged (mean and standard deviation) from a low of 116.28 ± 28.88 centimeters/second at the VA Group 1, to a high of 132.52 ± 36.04 centimeters/second at the VA Group 2. Variability of gait velocity was higher walking fast forward than walking forward at a usual speed.

Cadence (only GAITRite)

Cadence walking fast forward on the GAITRite remained relatively stable across medication states (Tables 29a-d). The range for cadence walking fast forward on the GAITRite OFF medications, ranged (mean and standard deviation) from a low of 133.47 ± 28.09 steps/minute in Galveston, to a high of 137.25 ± 23.42 steps/minute in the VA Group 1. The range for cadence walking fast forward on the GAITRite ON medications, ranged (mean and standard deviation) from a low of 131.52 ± 18.94 steps/minute in Galveston, to a high of 140.00 ± 25.92 steps/minute in the VA Group 1. If we discarded the data from the VA Group 1, where data was collected on the GAITRite version 3.3,

the range (mean and standard deviation) of cadence walking fast forward OFF medications was between 133.47 ± 28.09 steps/minute and 134.76 ± 16.90 steps/minute, and ON medications was between 131.52 ± 18.94 and 132.67 ± 14.73 steps/minute, essentially identical.

Stride Length (only GAITRite)

Walking fast forward on the GAITRite OFF medications, stride length ranged from a low of 106.77 ± 26.70 centimeters at the VA Group 1, to a high of 129.08 ± 26.01 centimeters at the VA Group 2. Walking on the GAITRite ON medications, stride length ranged (mean and standard deviation) from a low of 118.15 ± 22.95 centimeters at the VA Group 1, to a high of 136.30 ± 25.38 centimeters at the VA Group 2. Walking fast forward on the GAITRite stride length was significantly higher ON medications than OFF PD medications. As velocity increased, stride length accounted for most of the increase in speed (Tables 29a-d).

UPDRS Total Scores & UPDRS Motor Scores

Both UPDRS total and motor section scores improved, that is decreased from the OFF to the ON PD medication state in all sites (Tables 29a-d).

Correlations between Gait Parameters Walking Fast Forward & the UPDRS Total Score

Tables 30a-33a describe the correlations between gait parameters walking fast forward at all sites, in both medication conditions, and on both walking surfaces, and the UPDRS total score. None of the Spearman's rho correlations between the gait parameters and the UPDRS total score were greater than 0.7, both ON & OFF PD medications, and on the GAITRite and over ground. The Spearman's rho correlation coefficients were transformed, using a one tail Fisher's Z calculation, to generate a normal distribution and thus allow for easier comparison. We assumed a null hypothesis of $r < 0.05$, and an alpha set at $r < 0.05$ for the one sided Fisher's Z transformations at each site. In Galveston with

28 participants, the lowest Spearman's rho correlation that was statistically significant ($Z > 1.96$ thus the Spearman's rho significantly greater than 0.5) was 0.736. At the VA Group 1 with 21 subjects, the lowest Spearman's rho that reached statistical significance ($Z > 1.96$ thus Spearman's rho significantly greater than 0.5) was 0.766. At the VA Group 2 with 34 participants, the lowest Spearman's rho that reached statistical significance ($Z > 1.96$ thus Spearman's rho significantly greater than 0.5) was 0.712. Finally in the combined Galveston VA2 group with 64 subjects, the lowest Spearman's rho to reach significance ($Z > 1.96$ thus Spearman's rho significantly greater than 0.5) was 0.664. Across all sites there were no significant correlations between any gait parameter (velocity stride length or cadence) when walking fast forward and the UPDRS total score, regardless of medications state (OFF or ON).

Correlation between Gait Parameters Walking Fast Forward

The relationships between gait parameters walking fast forward, over both surfaces, and under both medications states, are summarized in Tables 30b-33b. There were significant correlations at all sites between velocity walking fast forward on the GAITRite ON & OFF PD medications, ranging from a low at Galveston ($r = 0.765$, 95% confidence interval 0.549 - 0.885) to a high at the VA Group 1 ($r = 0.812$, 95% confidence interval 0.586 - 0.920). The correlations at the other sites were close to the VA Group 1 level (Tables 30b -33b). The second correlation between ON & OFF PD medication states, was for velocity walking fast forward over ground at all sites with the exception of VA Group 1, that ranged from a low in the Galveston VA2 combined group ($r = 0.700$, 95% confidence interval 0.549 - 0.806), to a high at the VA Group 2 ($r = 0.827$, 95% confidence interval 0.685 - 0.908). The next two relationships were between walking on GAITRite and over ground in the same medications state. First OFF PD medications, there were correlations between velocity walking fast forward on the

GAITRite and walking over ground at two sites, that ranged from a low at the VA Group 1 ($r = 0.690$, 95% confidence interval 0.535 - 0.800), to a high at the VA Group 2 ($r = 0.94$, 95% confidence interval 0.856 - 0.975). Second, ON PD medications, there were strong correlations at all sites for velocity walking fast forward on the GAITRite and over ground, with a low at Galveston ($r = 0.736$, 95% confidence interval 0.501 - 0.870), to a high in the Galveston VA2 group ($r = 0.839$, 95% confidence interval 0.748 - 0.899). Similar to walking at a usual speed, there were a few single site associations between stride length and gait velocity walking fast forward on the GAITRite in the corresponding medication states (Tables 30b-33b).

Correlation between UPDRS & UPDRS Motor Scores Walking Fast Forward

The correlation between the UPDRS total score ON & OFF PD medications was excellent at all sites with the exception of group 1 at the VA (Tables 30b-33b). Correlations ranged from a low at the VA Group 2 ($r = 0.800$, 95% confidence interval 0.640 - 0.893), to a high in Galveston ($r = 0.824$, 95% confidence interval 0.652 - 0.915). Similarly the UPDRS motor score (section 3) was significantly correlated ON & OFF PD medications at two sites, the VA Group 2 ($r = 0.799$, 95% confidence interval 0.638 - 0.893), and the combined Galveston VA2 group ($r = 0.769$, 95% confidence interval 0.638 - 0.853). The UPDRS total score and the UPDRS motor section score were strongly correlated at all sites walking fast forward both OFF PD medications and ON PD medications. OFF medications, the lowest correlation between the UPDRS and UPDRS motor section was at the VA Group 1 ($r = 0.868$, 95% confidence interval 0.698 - 0.945), and highest at the VA Group 2 ($r = 0.930$, 95% confidence interval 0.867 - 0.963). ON medications, the lowest correlation between the UPDRS and UPDRS motor section was at the VA Group 1 ($r = 0.766$, 95% confidence interval 0.500 - 0.900), and highest at the VA Group 2 ($r = 0.952$, 95% confidence interval 0.908 - 0.975) (Tables 30b-33b).

Table 30a: Spearman's Rho Correlations Velocity Galveston Walking Fast Forward & UPDRS Total & Motor Scores

	GR fvel OFF	OG fvel OFF	GR fvel ON	OG fvel ON	GR fcad OFF	GR fcad ON	GR fSL OFF	GR fSL ON	UPDRS OFF	UPDRS ON	UPDRS M OFF	UPDRS M ON
GR fvel OFF	1.000											
OG fvel OFF	0.601	1.000										
GR fvel ON	0.765	0.652	1.000									
OG fvel ON	0.429	0.798	0.736	1.000								
GR fcad OFF	0.431	0.268	0.387	0.326	1.000							
GR fcad ON	0.247	0.351	0.443	0.450	0.713	1.000						
GR fSL OFF	0.788	0.649	0.607	0.357	0.033	0.029	1.000					
GR fSL ON	0.616	0.562	0.761	0.594	0.127	0.008	0.708	1.000				
UPDRS OFF	-0.073	-0.160	-0.197	-0.129	-0.001	-0.067	-0.109	-0.139	1.000			
UPDRS ON	-0.202	-0.001	-0.006	-0.049	-0.113	-0.055	-0.110	-0.081	0.824	1.000		
UPDRS M OFF	-0.051	-0.146	-0.223	-0.211	-0.023	-0.137	-0.148	-0.263	0.899	0.687	1.000	
UPDRS M ON	-0.220	-0.069	-0.032	-0.199	-0.208	-0.069	-0.029	-0.236	0.679	0.885	0.683	1.000

GR – GAITRite
 OG – over ground
 Fvel – fast velocity
 Fcad – fast cadence
 FSL – fast stride length
 UPDRS – Unified Parkinson's disease rating scale
Bold- significant correlation p<.05 with Fisher's Z transformation

None of the gait parameters were significantly correlated with the UPDRS total and UPDRS motor scores walking fast forward

Table 30b: Significant Correlations between Gait Parameters Galveston Walking Fast Forward

Variables	Spearman's Rho	Fisher Z	P	95% confidence interval
GR fvel off & GR fvel on	0.765	2.294	0.022	0.549-0.885
GR fvel off & GR fSL off	0.788	2.584	0.010	0.588-0.897
OG fvel off & OG fvel on	0.798	2.719	0.007	0.606-0.902
GR fvel on & OG fvel on	0.736	1.962	0.05	0.501-0.870
GR fvel on & OG fSL on	0.761	2.246	0.025	0.542-0.883
UPDRS off & UPDRS on	0.824	3.099	0.002	0.652-0.915
UPDRS off & UPDRS motor off	0.899	4.110	0.000	0.792-0.952
UPDRS on & UPDRS motor on	0.885	4.245	0.000	0.765-0.945

GR – GAITRite
 OG – over ground
 Fvel – fast velocity
 fSL – fast stride length
 UPDRS – Unified Parkinson's disease rating scale

Table 31a: Spearman’s Rho Correlations Velocity VA Group 1 Walking Fast Forward & UPDRS Total Motor Scores

	GR fvel OFF	OG fvel OFF	GR fvel ON	OG fvel ON	GR fcad OFF	GR fcad ON	GR ISL OFF	GR ISL ON	UPDRS OFF	UPDRS ON	UPDRS M OFF	UPDRS M ON
GR fvel OFF	1.000											
OG fvel OFF	0.940	1.000										
GR fvel ON	0.812	0.727	1.000									
OG fvel ON	0.600	0.642	0.791	1.000								
GR fcad OFF	0.356	0.317	0.226	0.131	1.000							
GR fcad ON	0.266	0.293	0.236	0.130	0.338	1.000						
GR ISL OFF	-0.037	-0.080	0.086	-0.042	0.513	0.304	1.000					
GR ISL ON	0.206	0.195	0.383	0.348	0.300	0.114	0.066	1.000				
UPDRS OFF	-0.063	-0.267	0.107	-0.028	0.038	0.124	-0.077	0.025	1.000			
UPDRS ON	0.040	-0.106	-0.046	-0.193	0.091	-0.004	-0.327	-0.249	0.672	1.000		
UPDRS M OFF	0.053	-0.109	0.194	0.045	0.052	0.132	-0.214	0.110	0.868	0.528	1.000	
UPDRS M ON	0.069	-0.082	-0.037	-0.034	0.199	0.028	-0.220	-0.195	0.683	0.766	0.699	1.000

Table 31b: Significant Correlations between Gait Parameters VA Group 1 Walking Fast Forward

Variables	Spearman’s Rho	Fisher Z	P	95% confidence interval
GR fvel off & OG fvel off	0.940	5.043	0.000	0.856-0.975
GR fvel off & GR fvel on	0.812	2.476	0.013	0.586-0.920
GR fvel on & OG fvel on	0.791	2.227	0.026	0.546-0.911
UPDRS off & UPDRS motor off	0.868	2.291	0.001	0.698-0.945
UPDRS on & UPDRS motor on	0.766	1.957	0.05	0.500-0.900

GR – GAITRite
 OG – over ground
 Fvel – fast velocity
 UPDRS – Unified Parkinson’s disease rating scale

Table 32a: Spearman's Rho Correlations Velocity VA Group 2 Walking Fast Forward & UPDRS Total Score & Motor Score

	GR fvel OFF	OG fvel OFF	GR fvel ON	OG fvel ON	GR fcad OFF	GR fcad ON	GR fsl OFF	GR fsl ON	UPDRS OFF	UPDRS ON	UPDRS M OFF	UPDRS M ON
GR fvel OFF	1.000											
OG fvel OFF	0.706	1.000										
GR fvel ON	0.811	0.684	1.000									
OG fvel ON	0.676	0.827	0.823	1.000								
GR fcad OFF	0.454	0.268	0.473	0.331	1.000							
GR fcad ON	0.018	0.120	0.051	0.021	0.390	1.000						
GR fsl OFF	0.661	0.492	0.494	0.451	0.074	-0.147	1.000					
GR fsl ON	0.664	0.546	0.582	0.573	0.114	-0.147	0.679	1.000				
UPDRS OFF	-0.340	-0.617	-0.271	-0.457	-0.036	-0.171	-0.405	-0.256	1.000			
UPDRS ON	-0.350	-0.575	-0.245	-0.417	-0.074	-0.200	-0.242	-0.214	0.800	1.000		
UPDRS M OFF	-0.331	-0.580	-0.243	-0.407	-0.065	-0.097	-0.464	-0.297	0.930	0.772	1.000	
UPDRS M ON	-0.320	-0.532	-0.231	-0.418	-0.016	-0.129	-0.284	-0.248	0.762	0.952	0.799	1.000

GAITrite

OG- over ground

Fvel – fast velocity

Fcad – fast cadence

FSI – fast stride length

UPDRS – Unified Parkinson's disease rating scale

UPDRSM – Unified Parkinson's disease rating scale motor section

Bold- significant correlation $p < .05$ with Fisher's Z transformation

None of the gait parameters correlated significantly with the UPDRS total score & UPDRS motor score walking fast forward

Table 32b: Significant Correlations between Gait Parameters VA Group 2 Walking Fast Forward

Variable	Spearman's Rho	Fisher Z	P	95% confidence interval
GR fvel off & GR fvel on	0.811	3.336	0.001	0.658-0.899
OG fvel off & OG fvel on	0.827	3.615	0.000	0.685-0.908
GR fvel on & OG fvel on	0.823	3.542	0.000	0.678-0.906
UPDRS off & UPDRS on	0.800	3.156	0.002	0.640-0.893
UPDRS off & UPDRS motor off	0.930	6.371	0.000	0.867-0.963
UPDRS off & UPDRS motor on	0.762	2.595	0.009	0.579-0.872
UPDRS on & UPDRS motor off	0.772	2.734	0.006	0.595-0.877
UPDRS on & UPDRS motor on	0.952	7.487	0.000	0.908-0.975
UPDRS motor off & UPDRS motor on	0.799	3.139	0.002	0.638-0.893

GR – GAITRite
 OG – over ground
 Fvel – fast velocity
 UPDRS – Unified Parkinson's disease rating scale

Table 33a: Spearman's Rho Correlations Velocity Galveston VA Group 2 Walking Fast Forward & UPDRS Total Score and UPDRS Motor Score

	GR fvel OFF	OG fvel OFF	GR fvel ON	OG fvel ON	GR fvel OFF	GR fvel ON	GR fvel OFF	GR fvel ON	UPDRS OFF	UPDRS ON	UPDRS M OFF	UPDRS M ON
GR fvel OFF	1.000											
OG fvel OFF	0.690	1.000										
GR fvel ON	0.806	0.700	1.000									
OG fvel ON	0.605	0.839	0.801	1.000								
GR fvel OFF	0.377	0.132	0.371	0.215	1.000							
GR fvel ON	0.163	0.120	0.122	0.129	0.202	1.000						
GR fvel OFF	0.503	0.448	0.369	0.367	0.010	0.355	1.000					
GR fvel ON	0.352	0.332	0.409	0.382	0.082	0.228	0.691	1.000				
UPDRS OFF	0.112	0.148	0.227	0.156	0.051	-0.129	0.031	-0.008	1.000			
UPDRS ON	0.036	0.142	0.126	0.078	-0.133	-0.147	0.003	-0.127	0.816	1.000		
UPDRS M OFF	0.139	0.074	0.191	0.074	-0.001	-0.146	0.029	-0.013	0.920	0.742	1.000	
UPDRS M ON	0.011	0.044	0.073	-0.010	-0.130	-0.196	0.005	-0.113	0.737	0.926	0.769	1.000

GR – GAITRite
 OG – over ground
 Fvel – fast velocity
 Fcad – fast cadence
 FSL – fast stride length
 UPDRS – Unified Parkinson's disease rating scale
 UPDRS M – Unified Parkinson's disease rating scale motor section
Bold- significant correlation p<.05 with Fisher Z transformation

None of the gait parameters were significantly correlated with the UPDRS total score & UPDRS motor score walking fast forward

Table 33b: Significant Correlations between Gait Parameters Galveston VA2 Walking Fast Forward

Variables	Spearman's Rho	Fisher's Z	P	95% confidence interval
GR fvel off & OG Fvel off	0.690	2.333	0.020	0.535-0.800
GR fvel off & GR fvel on	0.806	4.422	0.000	0.699-0.877
OG fvel off & OG fvel on	0.700	2.484	0.013	0.549-0.806
GR fvel on & OG fvel on	0.839	5.221	0.000	0.748-0.899
GR fSL off & GR fSL on	0.691	2.347	0.019	0.537-0.800
UPDRS off & UPDRS on	0.816	4.650	0.000	0.714-0.884
UPDRS off & UPDRS motor off	0.920	8.120	0.000	0.872-0.950
UPDRS off & UPDRS motor on	0.737	3.081	0.002	0.600-0.832
UPDRS on & UPDRS motor off	0.742	3.168	0.002	0.607-0.835
UPDRS on & UPDRS motor on	0.926	8.437	0.000	0.881-0.924
UPDRS motor off & UPDRS motor on	0.769	3.660	0.000	0.646-0.853

GR – GAITRite
 OG – Over ground
 Fvel – fast velocity
 FSL – fast stride length
 UPDRS – Unified Parkinson's disease rating scale

Walking Backward at a Comfortable Speed:

All gait parameters were measured on the GAITRite, and calculated for walking over ground, from measures of time and number of steps to walk 500 centimeters. Tables 34a-d describe the means and standard deviations for all gait variables walking backward and the UPDRS.

Velocity

Descriptive data for velocity at all sites is summarized in Tables 34a-d. Gait velocity walking backward was much slower than walking forward at all sites. Gait velocity walking backward was particularly slow at the VA Group 1, probably more than can be expected by disease severity alone. One needs to question whether this might in part be due to the use of GAITRite software version 3.3 (Cir, Havertown PA) where all

the other sites used GAITRite software version 3.9. When presenting the range of velocities across sites we will exclude the VA Group 1 where results were questionable. Walking on the GAITRite OFF medications, velocity ranged (mean and standard deviation) from a low of 50.23 ± 27.12 centimeters/second in Galveston, to a high of 66.70 ± 32.47 centimeters/second at the VA Group 2. Walking over ground and OFF medications, gait velocity ranged (mean and standard deviation) from a low of 54.79 ± 28.91 centimeters/second in Galveston, to a high of 67.06 ± 26.99 centimeters/second at the VA Group 2. Walking on the GAITRite OFF medications, gait velocity ranged (mean and standard deviation) from 61.78 ± 19.78 centimeters/second in Galveston, to 69.63 ± 29.61 centimeters/second at the VA Group 2. Finally walking over ground and ON medications gait velocity ranged (mean and standard deviation) from a low of 67.08 ± 22.10 centimeters/second in Galveston, to a high of 78.74 ± 34.16 centimeters/second in the VA Group 2. Gait velocity walking backward was significantly higher ON medications than OFF medications at all sites walking over ground, but only in Galveston walking on the GAITRite (Table 34e). Unlike walking forward where velocity was higher on the GAITRite, walking backward velocity was higher walking over ground, however this difference was significant only in the combined Galveston VA2 group ON medications.

Cadence

Descriptive data for cadence is presented in Tables 34a-d. Cadence did not change significantly walking backward on the GAITRite and over ground going from OFF to ON PD medications (Table 34f). Cadence at the VA did not seem to be out of line compared with the other sites. Walking backward on the GAITRite OFF medications, cadence ranged (mean and standard deviation) from a low in Galveston of 102.93 ± 38.82 steps/minute, to a high at the VA Group 1 of 114.14 ± 31.42 steps/minute. Walking

backward over ground OFF medications, cadence ranged (mean and standard deviation) from a low at the VA Group 1 of 112.14 ± 21.75 steps/minute, to a high at the VA Group 2 of 139.41 ± 33.03 steps/minute. ON medications cadence walking backward on the GAITRite ranged (mean and standard deviation) from a low of 109.89 ± 23.75 steps/minute in Galveston, to a high of 114.74 ± 28.06 steps/minutes at the VA Group 2. The difference in cadence values across all sites walking backward and on the GAITRite was approximately 5 steps/minute. Walking backward over ground ON medications, cadence ranged (mean and standard deviation) from a low of 117.41 ± 29.58 steps/minute at the VA Group 1, to a high of 130.91 ± 35.67 steps/minute at the VA Group 2.

Stride Length

Descriptive data for stride length walking backward is summarized in tables 34a-d. Stride length was considerably lower at the VA Group 1 than the other sites, both on the GAITRite and over ground, as well as ON & OFF PD medications. Given the large discrepancy between the VA Group 1 and the rest of the sites (15-20 centimeters), the remaining description of stride lengths walking backward will not include the VA Group 1. Over ground walking backward stride length was similar between all sites, both OFF (approximately 55 centimeters) and ON (approximately 67 centimeters) PD medications. Stride length measured on the GAITRite OFF medications, ranged (mean and standard deviation) from 59.21 ± 24.88 centimeters in Galveston, to 70.27 ± 28.84 centimeters at the VA Group 2. Stride length measured on the GAITRite ON medications, ranged (mean and standard deviation) from 69.36 ± 23.13 centimeters in Galveston, to 73.96 ± 24.36 centimeters at the VA Group 2. Stride length was longer ON medications than OFF medications; however this difference was only significant at the VA Group 1, both on the GAITRite and over ground (Table 34f). Stride length appeared to be longer on the GAITRite than over ground, and this was tested in specific aim 3.

Correlations between Gait Parameters Walking Backward & the UPDRS Total Score

Walking backward none of the Spearman's rho correlation coefficients between the gait parameters and the UPDRS total score were greater than 0.7, both ON & OFF PD medications, as well as on the GAITRite and over ground. Assuming a null hypothesis that $r > 0.5$ and setting alpha at 0.05, we transformed Spearman's rho correlation coefficients using a one tailed Fisher's Z so that the distribution would be the normal curve and allow for easier comparisons. In Galveston with 22 participants, the lowest Spearman's rho correlation to reach significance ($Z > 1.96$ thus Spearman's rho greater than 0.5) was 0.760. For the VA Group 1 with 13 subjects, the lowest correlation to reach significance ($Z > 1.96$ thus Spearman's rho greater than 0.5) was 0.824. At the VA Group 2 with 34 participants, the lowest Spearman's rho correlation to reach significance was 0.712. For the combined Galveston and VA2 group with 57 participants, the lowest Spearman's rho correlation to be statistically significant ($Z > 1.96$ thus Spearman's rho greater than 0.5) was 0.664. Tables 35a-38a summarize the Spearman's rho correlations between all backward walking gait parameters (velocity, cadence and stride length) and the UPDRS in both medications states and walking conditions. None of the Spearman's rho correlation coefficients between the gait variables and the UPDRS total score were greater than 0.7, both ON & OFF PD medications, and walking on the GAITRite or over ground. There were no significant correlations between any of the gait variables and the UPDRS in either medication state or walking condition walking backward.

Table 34a: Descriptive Statistics Galveston Walking Backward & UPDRS Total Score and UPDRS Motor Score

	N	Minimum	Maximum	Mean	Std. Deviation
GR bvel OFF (centimeters/second)	23	11.20	113.00	50.23	27.12
OG bvel OFF (centimeters/second)	23	19.80	136.80	54.79	28.91
GR bvel ON (centimeters/second)	23	27.60	98.70	61.78	19.78
OG bvel ON (centimeters/second)	22	22.20	119.80	67.08	27.10
GR bcad OFF (steps/minute)	23	48.40	194.90	102.93	38.82
OG bcad OFF (steps/minute)	23	53.00	171.60	117.95	28.06
GR bcad ON (steps/minute)	23	70.10	181.50	109.89	23.75
OG bcad ON (steps/minute)	22	91.80	173.10	124.56	23.31
GR bSL OFF (centimeters)	23	16.78	118.64	59.21	24.88
OG bSL OFF (centimeters)	23	25.58	129.41	52.95	22.89
GR bSL ON (centimeters)	23	39.57	112.30	69.36	23.13
OG bSL ON (centimeters)	22	26.51	129.41	66.08	28.43
UPDRS OFF	23	17.00	67.00	39.00	15.28
UPDRS ON	22	11.00	57.00	27.77	15.31
UPDRS M OFF	23	10.00	42.00	21.91	10.37
UPDRS M ON	22	4.00	36.00	13.36	9.19

GR – GAITRite
 OG – over ground
 bvel – backward velocity
 bcad – backward cadence
 bSL – backward stride length
 UPDRS – Unified Parkinson’s disease rating scale
 UPDRS M – Unified Parkinson’s disease rating scale motor section

Table 34b: Descriptive Statistics VA Group 1 Walking Backward & UPDRS Total Score and UPDRS Motor Score

	N	Minimum	Maximum	Mean	Std. Deviation
GR bvel OFF (centimeters/second)	12	9.65	84.30	38.03	22.78
OG bvel OFF (centimeters/second)	13	13.60	63.80	36.62	14.76
GR bvel ON (centimeters/second)	13	18.45	94.30	49.62	22.98
OG bvel ON (centimeters/second)	13	15.10	63.40	44.14	14.93
GR bcad OFF (steps/minute)	12	44.45	194.90	111.89	41.14
OG bcad OFF (steps/minute)	13	82.40	172.50	112.14	21.75
GR bcad ON (steps/minute)	13	51.30	157.20	109.99	27.51
OG bcad ON (steps/minute)	13	89.60	175.70	117.41	29.58
GR bSL OFF (centimeters)	12	17.72	93.25	42.41	24.21
OG bSL OFF (centimeters)	13	15.75	61.00	30.85	16.14
GR bSL ON (centimeters)	13	26.68	100.55	55.95	23.97
OG bSLON (centimeters)	13	13.33	83.33	48.21	19.55
UPDRS OFF	13	31.00	61.00	45.92	9.53
UPDRS ON	13	27.00	56.00	39.62	9.10
UPDRS M OFF	13	19.00	42.00	30.92	7.05
UPDRS M ON	13	16.00	37.00	22.62	6.56

GR – GAITRite
 OG – over ground
 bvel – backward velocity
 bcad – backward cadence
 bSL – backward stride length
 UPDRS – Unified Parkinson’s disease rating scale
 UPDRSM – Unified Parkinson’s disease rating scale motor section

Table 34c: Descriptive Statistics VA Group 2 Walking Backward & UPDRS Total & Motor Scores

	N	Minimum	Maximum	Mean	Std. Deviation
GR bvel OFF (centimeters/second)	36	21.20	198.70	66.70	32.47
OG bvel OFF (centimeters/second)	34	22.50	140.80	67.06	26.99
GR bvel ON (centimeters/second)	36	17.70	139.90	69.63	29.61
OG bvel ON (centimeters/second)	35	15.70	169.20	78.74	34.16
GR bcad OFF (steps/minute)	36	56.10	171.90	114.14	31.42
OG bcad OFF (steps/minute)	34	96.50	218.93	139.41	33.03
GR bcad ON (steps/minute)	36	57.80	191.90	114.74	28.06
OG bcad ON (steps/minute)	35	50.30	217.60	130.91	35.67
GR bSL OFF (centimeters)	36	24.69	179.76	70.27	28.84
OG bSL OFF (centimeters)	34	23.26	125.00	57.90	22.93
GR bSL ON (centimeters)	35	30.02	143.78	73.96	24.36
OG bSL ON (centimeters)	35	24.39	166.67	68.32	30.82
UPDRS OFF	36	15.00	94.00	45.08	18.09
UPDRS ON	36	13.00	59.00	33.08	11.89
UPDRS M OFF	36	6.00	66.00	27.67	13.02
UPDRS M ON	36	4.00	36.00	19.17	8.24

GR – GAITRite

OG – over ground

Bvel – backward velocity

Bcad – backward cadence

bSL – backward stride length

UPDRS – Unified Parkinson’s disease rating scale

UPDRS M – Unified Parkinson’s disease rating scale motor section

Table 34d: Descriptive Statistics Galveston VA Group 2 Walking Backward & UPDRS
Total & Motor Scores

	N	Minimum	Maximum	Mean	Std. Deviation
GR bvel OFF (centimeters/second)	59	11.20	198.70	60.28	31.31
OG bvel OFF (centimeters/second)	57	19.80	140.80	62.11	28.18
GR bvel ON (centimeters/second)	59	17.70	139.90	66.57	26.31
OG bvel ON (centimeters/second)	57	15.70	169.20	74.24	31.88
GR bcad OFF (steps/minute)	59	48.40	194.90	109.77	34.60
OG bcad OFF (steps/minute)	57	53.00	218.93	130.75	32.63
GR bcad ON (steps/minute)	59	57.80	191.90	112.85	26.36
OG bcad ON (steps/minute)	57	50.30	217.60	128.46	31.40
GR bSL OFF (centimeters)	59	16.78	179.76	65.96	27.68
OG bSL OFF (centimeters)	57	23.26	129.41	55.90	22.89
GR bSL ON (centimeters)	58	30.02	143.78	72.14	23.78
OG bSL ON (centimeters)	57	24.39	166.67	67.46	29.68
UPDRS OFF	59	15.00	94.00	42.71	17.17
UPDRS ON	58	11.00	59.00	31.07	13.41
UPDRS M OFF	59	6.00	66.00	25.42	12.29
UPDRS M ON	58	4.00	36.00	16.96	8.99

GR – GAITRite
OG – over ground
Bvel – backward velocity
Bcad – backward cadence
bSL – backward stride length
UPDRS – Unified Parkinson’s disease rating scale
UPDRS M – Unified Parkinson’s disease rating scale motor section

Table 34e: Paired T-Tests Velocity Walking Backward ON & OFF PD Medications

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Gal GR bvel OFF - Gal GR bvel ON	-11.56	21.93	4.57	-21.05	-2.08	-2.529	22	0.019
Pair 2	Gal OG bvel OFF- Gal OG bvel ON	-11.35	19.65	4.19	-20.06	-2.63	-2.708	21	0.013
Pair 3	VA1 GR bvel OFF - VA1 GR bvel ON	-4.83	24.88	5.56	-16.48	6.81	-.869	19	0.396
Pair 4	VA1 OG bvel OFF - VA1 OG bvel ON	-7.52	10.09	2.80	-13.61	-1.42	-2.686	12	0.020
Pair 5	VA2 GR bvel OFF - VA2 GR bvel ON	-3.53	37.59	6.18	-16.06	9.00	-.571	36	0.571
Pair 6	VA2 OG bvel OFF - VA2 OG bvel ON	-13.41	18.13	3.11	-19.73	-7.08	-4.314	33	0.000
Pair 7	GV2 GR bvel OFF- GV2 GRbvel ON	-6.61	32.52	4.20	-15.01	1.79	-1.575	59	0.121
Pair 8	GV2 OG bvel OFF- GV2 OG bvel ON	-12.60	18.59	2.48	-17.57	-7.62	-5.071	55	0.000

Gal – Galveston
 VA1 – VA Group 1
 VA2 – VA Group 2
 GV2 – Galveston VA combined group
 GR – GAITRite
 OG – over ground
 Bvel – backward velocity
Bold – significant p<.05

Table 34f: Paired T-Tests Cadence Walking Backward ON & OFF PD Medications

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Gal GR bcad OFF – Gal GR bcad ON	-6.96	31.01	6.47	-20.37	6.45	-1.076	22	0.294
Pair 2	Gal OG bcad OFF – Gal OG bcad ON	-5.73	20.06	4.28	-14.63	3.16	-1.340	21	0.194
Pair 3	VA1 bcad GR OFF- VA1 bcad GR ON	-.55	40.00	12.65	-29.17	28.07	-.043	9	0.966
Pair 4	VA1 bcad OG OFF- VA1 bcad OG ON	-10.08	23.92	7.56	-27.19	7.034	-1.332	9	0.216
Pair 5	VA2 GR bcad OFF - VA2 GR bcad ON	-.96	25.93	4.26	-9.61	7.69	-.225	36	0.823
Pair 6	VA2 OG bcad OFF - VA2 OG bcad ON	6.93	37.31	6.40	-6.08	19.95	1.084	33	0.286
Pair 7	GV2 GR bcad OFF - GV2 GR bcad ON	-3.26	27.89	3.60	-10.46	3.94	-.905	59	0.369
Pair 8	GV2 OG bcad OFF- GV2 OG bcad ON	2.33	45.98	6.78	-11.33	15.98	.343	45	0.733

Gal – Galveston
 VA1 –VA Group 1
 VA2 – VA Group 2
 GV2 – Galveston VA2 combined group
 GR – GAITRite
 OG – over ground
 Bcad – backward cadence
Bold – significant p<.05

Table 34g: Paired T-Tests Stride Length Walking Backward ON & OFF PD Medications

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Gal bSL GR OFF - Gal bSL GR ON	-9.58	22.48	4.79	-19.54	0.39	-1.998	21	0.059
Pair 2	Gal bSL OG OFF - Gal bSL OG ON	-13.51	17.59	3.84	-21.51	-5.50	-3.520	20	0.002
Pair 3	VA1 bSL GR OFF - VA1 bSL GR ON	-10.33	15.23	4.59	-20.57	0-.10	-2.249	10	0.048
Pair 4	VA1 bSL OG OFF - VA1 bSL OG ON	-17.57	32.26	9.73	-39.24	4.10	-1.807	10	0.101
Pair 5	VA2 bSL GR OFF - VA2 bSL GR ON	-2.87	34.39	5.73	-14.51	8.77	-.501	35	0.620
Pair 6	VA2 bSL OG OFF - VA2 bSL OG ON	-12.09	28.60	4.98	-22.23	-1.95	-2.428	32	0.021
Pair 7	GV2 bSL GR OFF - GV2 b SL GR ON	-5.41	30.39	3.99	-13.40	2.58	-1.357	57	0.180
Pair 8	GV2 bSL OG OFF - GV2 bSL OG ON	-12.64	24.72	3.36	-19.39	-5.89	-3.758	53	0.000

Gal – Galveston
VA1 – VA Group 1
VA2 – VA Group 2
GV2 – Galveston VA2 combined group
GR – GAITRite
OG – over ground
BSL – backward stride length
Bold – significant p<.05

Table 35a: Spearman's Rho Correlations Galveston Walking Backward & UPDRS Total Score

	GR b vel OFF	OG b vel OFF	GR b vel ON	OG b vel ON	GR b cad OFF	OG b cad OFF	GR b cad ON	OG b cad ON	GR bSL OFF	OG bSL OFF	GR bSL ON	OG bSL ON	UPDRS S OFF	UPDRS S ON
GR bvel OFF	1.000													
OG bvel OFF	0.770	1.000												
GR bvel ON	0.585	0.604	1.000											
OG bvel ON	0.601	0.727	0.793	1.000										
GR bcad OFF	0.694	0.427	0.153	0.066	1.000									
OG bcad OFF	0.490	0.567	0.209	0.057	0.617	1.000								
GR bcad ON	0.601	0.356	0.380	0.134	0.766	0.529	1.000							
OG bcad ON	0.446	0.407	0.088	0.124	0.622	0.684	0.443	1.000						
GR bSL OFF	0.699	0.675	0.699	0.800	0.009	0.109	0.129	0.106	1.000					
OG bSL OFF	0.598	0.794	0.604	0.774	0.161	0.067	0.133	0.097	0.699	1.000				
GR bSL ON	0.318	0.470	0.796	0.827	-0.241	-0.150	-0.168	-0.224	0.702	0.651	1.000			
OG bSL ON	0.407	0.501	0.726	0.901	-0.178	-0.249	-0.013	-0.280	0.735	0.711	0.861	1.000		
UPDRS S OFF	-0.132	-0.189	-0.415	-0.203	-0.051	-0.020	-0.223	-0.120	-0.248	-0.220	-0.233	-0.302	1.000	
UPDRS S ON	-0.014	-0.082	-0.338	-0.238	-0.232	-0.314	-0.040	-0.251	-0.239	-0.254	-0.345	-0.368	0.830	1.000

GR- GAITRite

OG – over ground

Bvel – backward velocity

Bcad – backward cadence

BSL – backward stride length

UPDRS – Unified Parkinson's disease rating scale

UPDRS M – Unified Parkinson's disease rating scale motor section

Bold- significant correlation p<.05 with Fisher's Z transformation

None of the gait parameters were significantly correlated with the UPDRS total score walking backward

Table 35b: Significant Correlations between Gait Parameters Galveston Walking
Backward

Variables	Spearman's Rho	Fisher Z	P	95% confidence intervals
GR bvel off & OG bvel off	0.770	2.053	0.040	0.507-0.901
OG bvel off & OG bSL off	0.794	2.323	0.020	0.560-0.910
GR bvel on & OG bvel on	0.793	2.311	0.021	0.558-0.910
OG bvel on & GR bSL off	0.800	2.394	0.017	0.571-0.913
GR bvel on & OG bSL off	0.774	2.096	0.036	0.524-0.901
OG bvel on & GR bSL on	0.827	2.743	0.006	0.623-0.925
OG bvel on & OG bSL on	0.901	4.046	0.000	0.774-0.958
GR bvel on & GR bSL on	0.766	2.011	0.044	0.509-0.897
GR bSL on & OG bSL on	0.861	3.260	0.001	0.690-0.941
UPDRS off & UPDRS on	0.830	2.785	0.005	0.629-0.927

GR – GAITRite
OG – over ground
bvel – backward velocity
bSL – backward stride length
bvel – backward cadence
UPDRS - Unified Parkinson's disease rating scale

Table 36a: Spearman's Rho Correlations VA Group 1 Walking Backward & UPDRS Total Score

	GR bvel OFF	OG bvel OFF	GR bvel ON	OG bvel ON	GR bcad OFF	OG bcad OFF	GR bcad ON	OG bcad ON	GR bSL OFF	OG bSL OFF	GR bSL ON	OG bSL ON	UPDRS OFF	UPDRS ON
GR bvel OFF	1.000													
OG bvel OFF	0.245	1.000												
GR bvel ON	0.748	0.214	1.000											
OG bvel ON	0.350	0.764	0.104	1.000										
GR bcad OFF	0.145	-0.119	-0.070	-0.196	1.000									
OG bcad OFF	0.371	0.110	0.192	0.352	0.259	1.000								
GR bcad ON	0.126	0.236	0.198	0.077	0.720	0.429	1.000							
OG bcad ON	0.063	0.104	0.324	0.390	0.245	0.560	0.275	1.000						
GR bSL OFF	0.392	0.189	0.266	0.021	0.255	0.608	0.140	0.182	1.000					
OG bSL OFF	-0.154	-0.911	-0.110	-0.669	0.161	0.220	0.275	0.129	0.098	1.000				
GR bSL ON	0.056	0.352	0.407	0.033	0.112	0.313	0.148	0.434	0.678	0.096	1.000			
OG bSL ON	0.446	0.840	0.190	0.691	-0.140	-0.185	-0.311	-0.240	-0.063	-0.927	-0.074	1.000		
UPDRS OFF	-0.310	-0.130	-0.157	-0.008	-0.214	-0.503	-0.442	-0.362	-0.577	-0.270	-0.094	0.226	1.000	
UPDRS ON	-0.176	-0.301	-0.003	-0.301	-0.158	-0.232	-0.270	-0.433	-0.503	-0.481	-0.406	-0.523	0.669	1.000

GR- GAITRite
 OG – over ground
 Bvel – backward velocity
 Bcad – backward cadence
 BSL – backward stride length
 UPDRS – Unified Parkinson's disease rating scale
 UPDRS M – Unified Parkinson's disease rating scale motor section
Bold- significant correlation p<.05 with Fisher Z transformation

None of the gait parameters were significantly correlated with the UPDRS total score walking backward

Table 36b: Significant Correlations between Gait Parameters VA Group 1 Walking Backward

Variables	Spearman's Rho	Fisher's Z	P	95% confidence interval
OG bvel off & OG bSL off	0.911	3.112	0.002	0.723-0.973
OG bvel off & OG bSL on	0.840	2.125	0.034	0.501-0.945
OG bSL off & OG bSL on	0.927	3.262	0.001	0.858-0.963

OG – over ground
 bvel – backward velocity
 bSL – backward stride length

Table 37a: Spearman's Rho Correlations VA Group 2 Walking Backward & UPDRS Total Score

	GR bvel OFF	OG bvel OFF	GR bvel ON	OG bvel ON	GR bcaad OFF	OG bcaad OFF	GR bcaad ON	OG bcaad ON	GR bSL OFF	OG bSL OFF	GR bSL ON	OG bSL ON	UPDRS OFF	UPDRS ON
GR bvel OFF	1.000													
OG bvel OFF	0.650	1.000												
GR bvel ON	0.392	0.472	1.000											
OG bvel ON	0.496	0.813	0.631	1.000										
GR bcaad OFF	0.588	0.157	0.377	0.154	1.000									
OG bcaad OFF	0.199	0.377	0.231	0.173	0.280	1.000								
GR bcaad ON	0.400	0.022	0.665	0.151	0.571	0.308	1.000							
OG bcaad ON	0.174	0.188	0.357	0.341	0.211	0.454	0.406	1.000						
GR bSL OFF	0.014	-0.072	-0.151	-0.150	-0.039	-0.036	-0.071	-0.002	1.000					
OG bSL OFF	-0.096	-0.131	-0.045	-0.113	-0.336	-0.085	-0.171	-0.004	-0.747	1.000				
GR bSL ON	0.157	0.188	0.232	0.293	0.052	0.033	0.101	0.077	0.573	0.737	1.000			
OG bSL ON	0.028	0.223	0.094	0.393	0.146	-0.052	-0.066	0.068	0.596	0.849	0.839	1.000		
UPDRS OFF	-0.308	-0.361	-0.253	-0.325	-0.170	-0.029	-0.061	-0.291	-0.321	-0.439	-0.451	-0.400	1.000	
UPDRS ON	-0.204	-0.126	-0.175	-0.211	-0.210	-0.042	-0.133	-0.309	-0.383	-0.391	-0.351	-0.337	0.800	1.000

GR- GAITRite

OG – over ground

Bvel – backward velocity

Bcaad – backward cadence

BSL – backward stride length

UPDRS – Unified Parkinson's disease rating scale

UPDRS M – Unified Parkinson's disease rating scale motor section

Bold- significant correlation p<.05 with Fisher's Z transformation

None of the gait parameters were significantly correlated in VA Group 2 with the UPDRS walking backward

Table 37b: Significant Correlations between Gait Parameters VA Group 2 Walking Backward

Variables	Spearman's Rho	Fisher's Z	P	95% confidence intervals
OG bvel off & OG bvel on	0.813	3.266	0.001	0.655-0.902
GR bSL off & OG bSL off	0.747	2.321	0.020	0.548-0.866
OG bSL off & GR bSL on	0.737	2.197	0.028	0.532-0.860
OG bSL off & OG bSL on	0.849	3.916	0.000	0.717-0.922
GR bSL on & OG bSL on	0.839	3.722	0.000	0.700-0.916
UPDRS off & UPDRS on	0.800	3.058	0.002	0.634-0.895

OG – over ground
 GR – GAITRite
 Bvel – backward velocity
 BSL – backward stride length
 UPDRS – Unified Parkinson's disease rating scale

Table 38a: Spearman's Rho Correlations Galveston VA Group 2 Walking Backward & UPDRS Total Score

	GR bvel OFF	OG bvel OFF	GR bvel ON	OG bvel ON	GR bcad OFF	OG bcad OFF	GR bcad ON	OG bcad ON	GR bSL OFF	OG bSL OFF	GR bSL ON	OG bSL ON	UPDRS OFF	UPDRS ON
GR bvel OFF	1.000													
OG bvel OFF	0.706	1.000												
GR bvel ON	0.483	0.556	1.000											
OG bvel ON	0.554	0.817	0.684	1.000										
GR bcad OFF	0.653	0.268	0.346	0.167	1.000									
OG bcad OFF	0.320	0.458	0.252	0.192	0.400	1.000								
GR bcad ON	0.469	0.146	0.562	0.152	0.638	0.398	1.000							
OG bcad ON	0.245	0.261	0.262	0.297	0.341	0.510	0.395	1.000						
GR bSL OFF	0.342	0.307	0.152	0.222	0.032	0.083	0.009	0.067	1.000					
OG bSL OFF	0.182	.432	0.168	0.364	0.121	0.010	0.090	0.026	0.729	1.000				
GR bSL ON	0.224	0.343	0.431	0.504	-0.073	-0.057	-0.037	-0.040	0.613	0.712	1.000			
OG bSL ON	0.178	0.346	0.308	0.559	-0.149	-0.118	-0.066	-0.072	0.640	0.794	0.858	1.000		
UPDRS OFF	-0.187	-0.243	-0.306	-0.253	-0.067	-0.025	-0.111	-0.136	-0.215	-0.309	-0.336	-0.356	1.000	
UPDRS ON	-0.095	-0.088	-0.220	-0.204	-0.020	-0.216	-0.044	-0.046	-0.285	-0.301	-0.344	-0.385	0.808	1.000

GR- GAITRite
 OG – over ground
 Bvel – backward velocity
 Bcad – backward cadence
 BSL – backward stride length
 UPDRS – Unified Parkinson's disease rating scale
 UPDRSM – Unified Parkinson's disease rating scale motor section
Bold- significant correlation p<.05 with Fisher's Z transformation

None of the gait parameters were significantly correlated in Galveston VA2 with the UPDRS total score

Table 38b: Significant Correlations between Gait Parameters Galveston VA2 Walking Backward

Variables	Spearman's Rho	Fisher's Z	P	95% confidence interval
GR bvel off & OG bvel off	0.706	2.424	0.015	0.546-0.816
OG bvel off & OG bvel on	0.817	3.397	0.000	0.707-0.888
GR bSL off & OG bSL off	0.729	2.722	0.006	0.579-0.831
GR bSL off & OG bSL on	0.794	3.916	0.000	0.673-0.872
GR bSL on & OG bSL on	0.858	5.411	0.000	0.770-0.914
UPDRS off & UPDRS on	0.808	4.203	0.000	0.694-0.882

OG – over ground

GR – GAITRite

Bvel – backward velocity

BSL – backward stride length

Correlations between Gait Parameters Walking Backward

There were several associations between walking backward on the GAITRite and walking backward over ground. First, walking backward OFF medications, there was a significant association between velocity over ground and on the GAITRite in Galveston ($r = 0.770$, 95% confidence interval 0.507 - 0.901), and at the VA Group 2 ($r = 0.706$, 95% confidence interval 0.546 - 0.816). Second, OFF medications, the correlation between stride length walking backward on the GAITRite and over ground was significant at the VA Group 2 ($r = 0.747$, 95% confidence interval 0.548 - 0.866), and in the combined Galveston and VA Group 2 ($r = 0.729$, 95% confidence interval 0.579 - 0.831). Third, walking backward ON medications, stride length on the GAITRite and over ground were related both in Galveston ($r = 0.861$, 95% confidence interval 0.690 - 0.941), at the VA Group 2 ($r = 0.839$, 95% confidence interval 0.700 - 0.916), and at the Galveston VA 2 group ($r = 0.858$, 95% confidence interval 0.770 - 0.916). Fourth, there was a strong association between stride length walking backward over ground ON & OFF PD medications at the VA Group 1 ($r = 0.927$, 95% confidence interval 0.858 - 0.963), and at the VA Group 2 ($r = 0.849$, 95% confidence interval 0.717 - 0.922). There

were several single site associations between stride length and velocity walking backward, and the reader is directed to Tables 35b-38b for further information.

Correlation between the UPDRS Scores Walking Backward

The UPDRS total score walking backward OFF medications was significantly correlated with the UPDRS total score walking backward ON medications in 3 sites – Galveston ($r = 0.830$, 95% confidence interval 0.629 - 0.920), the VA Group 2 ($r = 0.800$, 95% confidence interval 0.634 - 0.895), and at the combined Galveston VA group ($r = 0.808$, 95% confidence interval 0.694 - 0.882).

Hypothesis 4:

There will be a negative relationship (Spearman's $\rho < 0.7$) between GAITRite and over ground measures of velocity, cadence, and stride length, walking forward fast forward and backward, with the motor section of the UPDRS, both ON & OFF PD medications. The descriptive statistics for walking and the UPDRS motor section have been presented above, and can be found in Tables 24a-d for forward walking at a usual speed, Tables 29a-d for walking fast forward, and Tables 34a-d for walking backward. The correlations between the various gait parameters and the motor section of the UPDRS are presented in Tables 39a-42a for walking forward at a usual speed, Tables 30a-33a for walking fast forward and Tables 43a-46a for walking backward. The correlations between the gait parameters are presented in Tables 39b-42b for walking forward at a usual speed, Tables 30b-33b for walking fast forward and Tables 43b-46b for walking backward. None of the Spearman's ρ correlation coefficients between the gait parameters and the UPDRS motor section were greater than 0.7, both ON & OFF PD medications, while walking on the GAITRite or over ground. Assuming a null hypothesis of $r \leq 0.50$, with alpha set at 0.05, we transformed the Spearman's ρ correlation

coefficients using a one tailed Fisher's Z to produce a normal distribution, and allow for easier comparisons. There were no significant relationships between any gait parameter and the motor section of the UPDRS, regardless of medications state, walking speed, and walking direction. The relationships between the gait parameters have been discussed under hypothesis 3 above. Walking forward at a usual speed, the correlations between the UPDRS motor section ON & OFF PD Parkinson's medications were significant at the VA Group 2 ($r = 0.799$, 95% confidence interval 0.635 - 0.894), and in the combined Galveston VA2 group ($r = 0.683$, 95% confidence interval 0.526 - 0.795). Walking fast forward the relationship between the UPDRS motor section ON & OFF PD medications was significant at the VA Group 2 ($r = 0.799$, 95% confidence interval 0.635 - 0.894) and in the combined Galveston VA2 group ($r = 0.769$, 95% confidence interval 0.646 - 0.853). Finally walking backward, the correlation between the UPDRS motor section ON & OFF PD medications was significant at the VA Group 1 ($r = 0.865$, 95% confidence interval 0.579 - 0.961), at the VA group 2 ($r = 0.799$, 95% confidence interval 0.635 - 0.894), and in the combined Galveston VA2 group ($r = 0.764$, 95% confidence interval 0.629 - 0.854).

Summary Results of Specific Aim 1

The only balance measure with a Spearman's rho correlation greater than $r > 0.7$ was between the PIGD index OFF medications and the UPDRS OFF medications. There was a significant correlation between the PIGD index and the UPDRS total score when both were measured OFF PD medications. None of the balance measures made ON medications correlated significantly with the UPDRS total score. None of the balance measures were significantly correlated with the UPDRS motor score regardless of medications status. None of the gait variables measured (velocity, cadence, stride length)

were significantly related to the UPDRS total score, when walking forward at a usual speed, walking fast forward, and walking backward, while on the GAITRite or over ground at all sites, regardless of medication state. Similarly, none of the gait variables measured (velocity, cadence, stride length) were significantly related to the UPDRS motor score, when walking forward at an usual and fast speed or walking backward, both on the treadmill and over ground, ON & OFF PD medications. There were several correlations between gait parameters ON & OFF PD medications, most notably, stride length walking forward and backward, and velocity walking fast forward on GAITRite and over ground. There were also significant correlations between walking on the GAITRite and over ground specifically, velocity walking forward fast forward and backward OFF medications, velocity walking fast forward ON medications, and stride length walking forward OFF and backward ON medications.

SPECIFIC AIM 2 was to determine the degree to which performance and self-perceived measures of balance, used for patients with PD, correlated with each other, both when the patient was ON & OFF PD medications.

Our hypothesis was that there would be a negative correlation (Spearman rho < 0.7) between the performance-based measures of balance (5 step, timed 360 degree turning, PIGD index, and GABS), and self-perceived measures of balance (Activities Specific Balance Confidence Scale), both when the patient was ON & OFF PD medications.

Table 47 summarizes the descriptive statistics for the performance and self-perceived balance measures. All balance measures improved from the OFF to the ON medication state. Scores on the GABS decreased 8.15 points, such that mean and standard deviation changed from 29.72 ± 15.10 to 21.5 ± 12 . Time to step up and down 5 steps decreased 3.14 seconds, such that mean and standard deviation changed from 14.66

± 6.65 to 11.52 ± 3.66 seconds. Turning 360 degrees decreased approximately 2 seconds between ON & OFF PD medication states, however the variability was high particularly for turning left. The PIGD index changed the least decreasing approximately 1.5 points from the OFF to ON state, such that mean and standard deviation changed from 6.83 ± 3.21 to 5.32 ± 2.79 points.

Correlations between Self-Perceived and Performance Measures of Balance

Table 48a summarizes the correlations between the performance balance measures and the self-perceived ABC scale. None of Spearman's rho correlations between the ABC and the performance based measures was greater than -0.7, with the exception of the GABS OFF medication. In order to change Spearman's rho distribution to the known normal distribution, we transformed the Spearman's rho correlation coefficients using a one tailed Fisher's Z, with alpha set at 0.05. We assumed a null hypothesis of $r \leq 0.5$ and set alpha at 0.05. Thus with 83 participants the lowest Spearman's rho correlation to reach statistical significance ($Z > 1.96$ thus $r > 0.5$) was 0.646. The performance balance measures that correlated significantly with the self-perceived ABC scale OFF PD medications included the GABS ($r = -0.732$, 95% confidence interval -0.614 to -0.818), turn 360 degrees to the right ($r = -0.659$, 95% confidence interval -0.517 to -0.765), and the PIGD index OFF medications ($r = -0.656$, 95% confidence interval -0.513 to -0.763). There were no performance balance measures that correlated with the ABC scale when the participants were ON their PD medications.

Table 39a: Spearman's Rho Correlations Galveston Walking Forward Usual Speed & UPDRS Motor Score

	GR vel OFF	OG vel OFF	GR vel ON	OG vel ON	GR cad OFF	OG cad OFF	GR cad ON	OG cad ON	GR SL OFF	OG SL OFF	GR SL ON	OG SL ON	UPDRS M OFF	UPDRS M ON
GR vel OFF	1.000													
OG vel OFF	0.374	1.000												
GR vel ON	0.515	0.395	1.000											
OG vel ON	0.365	0.680	0.527	1.000										
GR cad OFF	0.612	0.251	0.255	0.143	1.000									
OG cad OFF	0.228	0.349	0.213	0.075	0.390	1.000								
GR cad ON	0.438	0.008	0.413	0.205	0.488	0.193	1.000							
OG cad ON	0.279	0.272	0.065	0.492	0.253	0.241	0.089	1.000						
GR SL OFF	0.673	0.424	0.644	0.561	0.288	0.164	0.219	0.221	1.000					
OG SL OFF	0.524	0.735	0.610	0.472	0.213	0.117	0.196	0.108	0.572	1.000				
GR SL ON	0.402	0.474	0.893	0.722	0.046	0.160	0.063	0.106	0.660	0.569	1.000			
OG SL ON	0.343	0.413	0.645	0.473	0.079	0.001	0.010	0.334	0.497	0.788	0.678	1.000		
UPDRS M OFF	-0.178	-0.125	-0.254	-0.005	-0.047	-0.116	-0.119	-0.066	-0.081	-0.047	-0.202	0.039	1.000	
UPDRS M ON	-0.255	-0.142	-0.153	-0.027	-0.223	-0.082	-0.005	-0.011	-0.189	-0.109	-0.113	-0.065	0.683	1.000

GR- GAITRite

OG – over ground

vel – velocity

cad – cadence

SL – stride length

UPDRS M – Unified Parkinson's disease rating scale motor section

Bold- significant correlation p<.05 with a Fisher's Z transformation

None of the gait parameters were significantly correlated in Galveston with the UPDRS motor score

Table 39b: Significant Correlations between Gait Parameters Galveston Walking Forward

Variables	Spearman's Rho	Fisher's Z	P	95% confidence interval
OG vel off & OG SL off	0.735	1.951	0.05	0.499-0.869
OG SL off & OG SL on	0.788	2.584	0.010	0.588-0.897
GR vel on & GR SL on	0.893	4.436	0.000	0.780-0.949

OG – over ground

GR – GAITRite

Vel – velocity

SL - stride length

UPDRS M – Unified Parkinson's disease rating scale motor section

Table 40a: Spearman’s Rho Correlations VA Group 1 Walking Forward Usual Speed & UPDRS Motor Section

	GR vel OFF	OG vel OFF	GR vel ON	OG vel ON	GR cad OFF	OG cad OFF	GR cad ON	OG cad ON	GR SL OFF	OG SL OFF	GR SL ON	OG SL ON	UPDRS M OFF	UPDRS M ON
GR vel OFF	1.000													
OG vel OFF	0.848	1.000												
GR vel ON	0.696	0.682	1.000											
OG vel ON	0.552	0.656	0.563	1.000										
GR cad OFF	0.447	0.441	0.495	0.090	1.000									
OG cad OFF	0.087	0.140	0.011	0.122	0.007	1.000								
GR cad ON	0.304	0.377	0.543	0.313	0.669	0.128	1.000							
OG cad ON	0.266	0.355	0.046	0.004	0.054	0.481	0.317	1.000						
GR SL OFF	0.234	0.218	0.111	0.183	0.232	0.388	0.249	0.169	1.000					
OG SL OFF	0.650	0.637	0.643	0.587	0.260	-0.074	0.330	0.169	0.311	1.000				
GR SL ON	0.049	0.070	0.095	0.181	0.153	0.013	0.301	0.023	0.728	0.299	1.000			
OG SL ON	0.298	0.345	0.217	0.691	0.010	0.084	0.082	0.328	0.126	0.638	0.331	1.000		
UPDRS M OFF	-0.152	-0.023	-0.080	-0.147	-0.100	-0.255	-0.058	-0.227	-0.319	-0.198	-0.242	-0.125	1.000	
UPDRS M ON	-0.007	-0.019	-0.003	-0.001	-0.107	-0.020	-0.002	-0.084	-0.186	-0.264	-0.093	-0.095	0.699	1.000

GR- GAITRite
 OG – over ground
 vel – velocity
 cad –cadence
 SL – backward stride length
 UPDRS M – Unified Parkinson’s disease rating scale motor section
Bold- significant correlation p<.05 with Fisher’s Z transformation

None of the gait parameters at the VA Group 1 walking forward correlated significantly with the UPDRS motor scores

Table 40b: Significant Correlations between Gait Parameters VA Group1 Walking Forward

Variable	Spearman’s Rho	Fisher’s Z	P	95% confidence interval
GR vel off & OG vel off	0.848	3.050	0.010	0.588-0.897

GR – GAITRite
 OG – over ground
 Vel – velocity

Table 41a: Spearman’s Rho Correlations VA Group 2 Walking Forward Usual Speed & UPDRS Motor Section

	GR vel OFF	OG vel OFF	GR vel ON	OG vel ON	GR cad OFF	OG cad OFF	GR cad ON	OG cad ON	GR SL OFF	OG SL OFF	GR SL ON	OG SL ON	UPDRS M OFF	UPDRS M ON
GR vel OFF	1.000													
OG vel OFF	0.578	1.000												
GR vel ON	0.676	0.599	1.000											
OG vel ON	0.615	0.828	0.674	1.000										
GR cad OFF	0.292	0.030	0.260	0.492	1.000									
OG cad OFF	0.342	0.589	0.519	0.647	0.465	1.000								
GR cad ON	0.104	0.012	0.160	0.045	0.247	0.119	1.000							
OG cad ON	0.250	0.206	0.109	0.185	0.048	0.027	0.064	1.000						
GR SL OFF	0.823	0.605	0.606	0.639	0.046	0.188	0.068	0.328	1.000					
OG SL OFF	0.584	0.784	0.480	0.670	0.163	0.182	0.187	0.292	0.827	1.000				
GR SL ON	0.405	0.347	0.549	0.508	0.075	0.108	0.198	0.107	0.503	0.451	1.000			
OG SL ON	0.073	0.150	0.024	0.221	0.021	0.134	0.158	0.207	0.039	0.125	0.049	1.000		
UPDRS M OFF	-0.474	-0.599	-0.231	-0.383	-0.217	-0.087	-0.268	-0.328	-0.538	-0.581	-0.187	-0.085	1.000	
UPDRS M ON	-0.345	-0.474	-0.194	-0.391	-0.019	-0.171	-0.245	-0.253	-0.421	-0.411	-0.075	-0.210	-0.799	1.000

GR- GAITRite
 OG – over ground
 vel – backward velocity
 cad –cadence
 SL –stride length
 UPDRSM – Unified Parkinson’s disease rating scale motor section
Bold- significant correlation p<.05 with Fisher’s Z transformation

None of the gait parameters were significantly correlated in the VA Group 2 walking forward and the UPDRS motor section

Table 41b: Significant Correlations between Gait Parameters VA Group 2 Walking Forward

Variables	Spearman’s Rho	Fisher’s Z	P	95% confidence interval
GR vel off & GR SL off	0.823	2.584	0.000	0.675-0.907
OG vel off & OG vel on	0.828	3.578	0.000	0.684-0.910
OG vel off & OG SL off	0.784	2.864	0.004	0.611-0.885
GR SL off & OG SL off	0.827	3.560	0.000	0.682-0.909
UPDRS motor off & UPDRS motor on	0.799	3.092	0.002	0.635-0.894

GR – GAITRite
 OG – over ground
 Vel – velocity
 SL – stride length
 UPDRS – Unified Parkinson’s disease rating scale

Table 42a: Spearman’s Rho Correlations Galveston VA Group 2 Walking Forward Usual Speed & UPDRS Motor Section

	GR vel OFF	OG vel OFF	GR vel ON	OG vel ON	GR cad OFF	OG cad OFF	GR cad ON	OG cad ON	GR SL OFF	OG SL OFF	GR SL ON	OG SL ON	UPDRS M OFF	UPDRS M ON
GR vel OFF	1.000													
OG vel OFF	0.518	1.000												
GR vel ON	0.637	0.551	1.000											
OG vel ON	0.580	0.771	0.657	1.000										
GR cad OFF	-0.016	-0.123	-0.084	-0.109	1.000									
OG cad OFF	-0.078	-0.073	-0.071	-0.029	-0.481	1.000								
GR cad ON	0.010	0.038	0.082	0.205	0.084	0.071	1.000							
OG cad ON	0.131	0.089	0.149	0.087	0.259	0.203	0.034	1.000						
GR SL OFF	0.079	0.072	0.030	0.152	0.081	0.204	0.230	0.281	1.000					
OG SL OFF	0.001	0.102	0.055	0.168	.059	0.107	0.221	0.061	0.655	1.000				
GR SL ON	0.071	0.059	0.083	0.147	0.018	0.159	0.131	0.120	0.574	0.470	1.000			
OG SL ON	0.145	0.003	0.053	0.205	0.065	0.078	0.138	0.153	0.589	0.688	0.605	1.000		
UPDRS M OFF	-0.081	-0.291	-0.168	-0.156	-0.051	-0.048	-0.141	-0.159	-0.031	-0.108	-0.069	-0.230	1.000	
UPDRS M ON	-0.063	-0.213	-0.080	-0.131	-0.082	-0.175	-0.177	-0.294	-0.031	-0.157	-0.146	-0.172	-0.769	1.000

GR- GAITRite

OG – over ground

vel – velocity

cad –cadence

SL –stride length

UPDRSM – Unified Parkinson’s disease rating scale motor section

Bold- significant correlation p<.05 with Fisher’s Z transformation

None of the gait parameters were significantly correlated at Galveston VA2 Group walking forward with the UPDRS motor score

Table 42b: Significant Correlations between Gait Parameters Galveston VA Group 2 Walking Forward

Variables	Spearman’s Rho	Fisher’s Z	P	95% confidence interval
OG vel off & OG vel on	0.680	2.185	0.029	0.522-0.793
OG SL off & OG SL on	0.788	4.037	0.000	0.673-0.866
UPDRS motor off & UPDRS motor on	0.683	2.229	0.026	0.526-0.795

GR – GAITRite

OG – over ground

Vel – velocity

SL – stride length

UPDRS – Unified Parkinson’s disease rating scale

Table 43a: Spearman’s Rho Correlations Galveston Walking Backward and UPDRS Motor Section

	GR bvel OFF	OG bvel OFF	GR bvel ON	OG bvel ON	GR bcad OFF	GR bcad ON	OG bcad OFF	OG bcad ON	GR bSL OFF	OG bSL OFF	GR bSL ON	OG bSL ON	UPDRS M OFF	UPDRS M ON
GR bvel OFF	1.000													
OG bvel OFF	0.770	1.000												
GR bvel ON	0.585	0.604	1.000											
OG bvel ON	0.601	0.727	0.793	1.000										
GR bcad OFF	0.694	0.427	0.153	0.066	1.000									
GR bcad ON	0.601	0.356	0.380	0.134	0.766	1.000								
OG bcad OFF	0.490	0.567	0.209	0.057	0.617	0.529	1.000							
OG bcad ON	0.446	0.407	0.088	0.124	0.622	0.443	0.684	1.000						
GR bSL OFF	0.699	0.675	0.699	0.800	0.009	0.129	0.109	0.106	1.000					
OG bSL OFF	0.598	0.794	0.604	0.774	0.161	0.133	0.067	0.097	0.699	1.000				
GR bSL ON	0.318	0.470	0.796	0.827	-0.241	-0.168	-0.150	-0.224	0.702	0.651	1.000			
OG bSL ON	0.407	0.501	0.726	0.901	0.178	0.013	0.249	0.280	0.735	0.711	0.861	1.000		
UPDRS M OFF	- 0.180	-0.154	-0.526	-0.208	-0.036	-0.380	-0.101	-0.085	-0.263	-0.142	-0.239	-0.300	1.000	
UPDRS M ON	- 0.168	-0.072	-0.470	-0.336	-0.189	-0.050	-0.298	-0.252	-0.392	-0.221	-0.426	-0.483	0.677	1.000

GR- GAITRite

OG – over ground

bvel – backward velocity

bcad – backward cadence

SL –stride length

UPDRS M – Unified Parkinson’s disease rating scale motor section

Bold- significant correlation p<.05 with Fisher Z transformation

None of the gait parameters were significantly correlated with the UPDRS motor score walking backward in Galveston

Table 43b: Significant Correlations between Gait Parameters Galveston Walking Backward

Variables	Spearman's Rho	Fisher's Z	P	95% confidence interval
GR bvel off & OG bvel off	0.770	3.461	0.001	0.516-0.899
OG bvel off & OG bSL off	0.794	3.916	0.000	0.560-0.910
GR bvel on & OG bvel on	0.793	3.896	0.000	0.558-0.910
GR bvel on & GR bSL on	0.796	3.956	0.000	0.564-0.911
OG bvel on & GR bSL off	0.800	4.037	0.000	0.571-0.913
OG bvel on & OG bSL off	0.774	3.534	0.000	0.524-0.901
OG bvel on & GR bSL on	0.827	4.624	0.000	0.623-0.925
OG bvel on & OG bSL on	0.901	6.821	0.000	0.774 -0.958
GR bcad off & GR bcad on	0.766	3.390	0.001	0.509 -0.897
GR bSL on & OG bSL on	0.861	5.496	0.000	0.690 -0.941

GR – GAITRite
 OG - over ground
 Bvel – backward velocity
 BSL – backward stride length
 Bcad – backward cadence

Table 44a: Spearman's Rho Correlations VA Group 1 Walking Backward & UPDRS Motor Section

	GR bvel OFF	OG bvel OFF	GR bvel ON	OG bvel ON	GR bcad OFF	OG bcad OFF	GR bcad ON	OG bcad ON	GR bSL OFF	OG bSL OFF	GR bSL ON	OG bSL ON	UPDRS M OFF	UPDRS M ON
GR bvel OFF	1.000													
OG bvel OFF	0.245	.0001												
GR bvel ON	0.748	0.214	1.000											
OG bvel ON	0.350	0.764	0.104	1.000										
GR bcad OFF	0.145	-0.119	-0.070	-0.196	1.000									
OG bcad OFF	0.371	0.110	0.192	0.352	0.259	1.000								
GR bcad ON	0.126	0.236	0.198	0.077	0.720	0.429	1.000							
OG bcad ON	0.063	0.104	0.324	0.390	0.245	0.560	0.275	1.000						
GR bSL OFF	0.392	0.189	0.266	0.021	0.255	0.608	0.140	0.182	1.000					
OG bSL OFF	0.154	0.911	0.110	0.669	0.161	0.220	0.275	0.129	0.098	1.000				
GR bSL ON	0.056	0.352	0.407	0.033	0.112	0.313	0.148	0.434	0.678	0.096	1.000			
OG bSL ON	0.446	0.840	0.190	0.691	-0.140	-0.185	-0.311	-0.240	-0.063	-0.927	-0.074	1.000		
UPDRS M OFF	-0.550	-0.217	-0.308	-0.118	-0.378	-0.501	-0.451	-0.135	-0.543	-0.358	-0.039	-0.194	1.000	
UPDRS M ON	-0.435	-0.103	-0.361	-0.239	-0.560	-0.372	-0.505	-0.031	-0.527	-0.257	-0.186	-0.145	0.865	1.000

GR- GAITRite
 OG – over ground
 bvel – backward velocity
 bcad – backward cadence
 SL –stride length
 UPDRS M – Unified Parkinson's disease rating scale motor section
Bold- significant correlation p<.05 with Fisher's Z transformation

None of the gait parameters walking backward at VA Group 1 were significantly correlated with the UPDRS motor score

Table 44b: Significant Correlations between Gait Parameters VA Group 1 Walking Backward

Variables	Spearman's Rho	Fisher's Z	P	95% confidence interval
OG bvel off & OG bSL off	0.911	2.592	0.003	0.707-0.975
OG bvel off & OG bSL on	0.840	2.016	0.044	0.514-0.953
OG bSL off & OG bSL on	0.927	3.262	0.001	0.755-0.979
UPDRS motor off & UPDRS motor on	0.865	2.291	0.022	0.579-0.961

OG – over ground
 GR – GAITRite
 Bvel – backward velocity
 BSL – backward stride length
 UPDRS – Unified Parkinson's disease rating scale

Table 45a: Spearman's Rho Correlations VA Group 2 Walking Backward & UPDRS Motor Section

	GR bvel OFF	OG bvel OFF	GR bvel ON	OG bvel ON	GR bcad OFF	OG bcad OFF	GR bcad ON	OG bcad ON	GR bSL OFF	OG bSL OFF	GR bSL ON	OG bSL ON	UPDRS M OFF	UPDRS M ON
GR bvel OFF	1.000													
OG bvel OFF	0.650	1.000												
GR bvel ON	0.392	0.472	1.000											
OG bvel ON	0.496	0.813	0.631	1.000										
GR bcad OFF	0.588	0.157	0.377	0.154	1.000									
OG bcad OFF	0.199	0.377	0.231	0.173	0.280	1.000								
GR bcad ON	0.400	0.022	0.665	0.151	0.571	0.308	1.000							
OG bcad ON	0.174	0.188	0.357	0.341	0.211	0.454	0.406	1.000						
GR bSL OFF	0.641	0.741	0.246	0.565	-0.141	-0.033	-0.031	0.078	1.000					
OG bSL OFF	-0.523	-0.798	-0.295	-0.704	0.076	0.151	0.255	0.122	0.747	1.000				
GR bSL ON	0.217	0.586	0.831	0.704	0.100	0.076	0.213	0.144	0.324	.0549	1.000			
OG bSL ON	0.476	0.731	0.504	0.875	0.050	0.167	0.024	0.054	0.596	0.849	0.699	1.000		
UPDRS M OFF	-0.290	-0.309	-0.184	-0.278	-0.145	-0.050	-0.034	-0.296	-0.331	-0.255	-0.182	-0.256	1.000	
UPDRS M ON	-0.120	-0.056	-0.093	-0.180	-0.156	-0.044	-0.105	-0.316	-0.092	-0.036	-0.004	-0.119	-0.799	1.000

GR- GAITRite
 OG – over ground
 bvel – backward velocity
 bcad – backward cadence
 SL –stride length
 UPDRS M – Unified Parkinson's disease rating scale motor section
Bold- significant correlation p<.05 with Fisher's Z transformations
 None of the gait parameters walking backward in Galveston were significantly correlated with the UPDRS motor score

Table 45b: Significant Correlations between Gait Parameters VA Group 2 Walking Backward

Variables	Spearman's Rho	Fisher's Z	P	95% confidence interval
OG bvel off & OG bvel on	0.813	5.496	0.001	0.650-0.901
OG bvel off & GR bSL off	0.741	2.282	0.022	0.542-0.861
OG bvel off & OG bSL off	0.798	3.076	0.002	0.634-0.893
OG bvel off & OG bSL on	0.731	2.158	0.031	0.526-0.855
GR bvel on & OG bSL on	0.831	3.632	0.000	0.689-0.911
OG bvel on & OG bSL on	0.875	4.522	0.000	0.765-0.935
GR bSL off & OG bSL off	0.747	2.358	0.018	0.551-0.864
OG bSL off & OG bSL on	0.849	3.978	0.000	0.720-0.921
UPDRS motor off & UPDRS motor on	0.799	3.092	0.002	0.635-0.894

GR – GAITRite
 OG – over ground
 Bvel – backward velocity
 bSL – backward stride length
 UPDRS – Unified Parkinson's disease rating scale

Table 46a: Spearman's Rho Correlations Galveston VA Group 2 Walking Backward & UPDRS Motor Section

	GR bvel OFF	OG bvel OFF	GR bvel ON	OG bvel ON	GR bcad OFF	OG bcad OFF	GR bcad ON	OG bcad ON	GR bSL OFF	OG bSL OFF	GR bSL ON	OG bSL ON	UPDRS M OFF	UPDRS M ON
GR bvel OFF	1.000													
OG bvel OFF	0.706	1.000												
GR bvel ON	0.483	0.556	1.000											
OG bvel ON	0.554	0.817	0.684	1.000										
GR bcad OFF	0.653	0.268	0.346	0.167	1.000									
OG bcad OFF	0.320	0.458	0.252	0.192	0.400	1.000								
GR bcad ON	0.469	0.146	0.562	0.152	0.638	0.398	1.000							
OG bcad ON	0.245	0.261	0.262	0.297	0.341	0.510	0.395	1.000						
GR bSL OFF	0.692	0.734	0.408	0.641	0.022	0.077	0.042	0.086	1.000					
OG bSL OFF	-0.297	-0.362	-0.168	-0.328	-0.118	-0.180	-0.025	-0.050	-0.319	1.000				
GR bSL ON	0.286	0.571	0.821	0.745	0.000	0.017	0.056	0.017	0.468	0.173	1.000			
OG bSL ON	0.455	0.661	0.586	0.869	-0.022	-0.164	-0.032	-0.059	-0.640	-0.267	0.775	1.000		
UPDRS M OFF	-0.176	-0.140	-0.274	-0.195	-0.078	-0.011	-0.141	-0.118	-0.189	-0.096	-0.188	-0.258	1.000	
UPDRS M ON	-0.070	-0.010	-0.186	-0.185	-0.059	-0.242	-0.029	-0.061	-0.154	-0.306	-0.175	-0.264	-0.764	1.000

GR- GAITRite
 OG – over ground
 bvel – backward velocity
 bcad – backward cadence
 SL –stride length
 UPDRS M – Unified Parkinson's disease rating scale motor section
Bold- significant correlation p<.05 with Fisher's Z transformation

None of the gait parameters at the VA group 2 walking backward were significantly correlated with the UPDRS motor score

Table 46b: Significant Correlations between Gait Parameters Galveston VA2 Group Walking Backward

Variables	Spearman's Rho	Fisher's Z	P	95% confidence interval
GR bvel off & OG bvel off	0.706	2.424	0.015	0.540 -0.816
GR bvel off & OG bSL off	0.692	2.223	0.026	0.520 -0.807
OG bvel off & OG bvel on	0.817	4.397	0.000	0.700 -0.888
OG bvel off & GR bSL off	0.734	2.851	0.004	0.586-0.834
GR bvel on & OG bvel on	0.684	2.111	0.035	0.516-0.801
GR bvel on & GR bSL on	0.821	4.487	0.000	0.713-0.890
OG bvel on & GR bSL on	0.745	3.030	0.002	0.602-0.842
OG bvel on & OG bSL on	0.869	5.730	0.000	0.787-0.921
GR bSL on & OG bSL on	0.775	3.522	0.000	0.645-0.861
UPDRS motor off & UPDRS motor on	0.764	3.354	0.001	0.629-0.854

GR – GAITRite
 OG – over ground
 Bvel – backward velocity
 BSL – backward stride length
 UPDRS – Unified Parkinson's disease rating scale

Table 47: Descriptive Statistics Performance-Based and Self-perceived Balance Measures

	N	Minimum	Maximum	Mean	Std. Deviation
GABS OFF	88	5.00	64.00	29.72	15.10
GABS ON	87	0.00	63.00	21.57	12.91
Five step OFF seconds	83	7.45	48.26	14.66	6.65
Five step ON seconds	83	6.30	30.45	11.52	3.66
Turn left OFF seconds	84	2.00	105.59	6.86	11.37
Turn left ON seconds	83	1.98	53.44	4.80	5.76
Turn right OFF seconds	85	2.13	114.85	7.36	12.39
Turn right ON seconds	84	1.86	112.39	5.50	11.98
PIGD OFF	88	2.00	17.00	6.83	3.21
PIGD ON	88	1.00	13.00	5.32	2.79
ABC (%)	87	14.38	98.13	67.64	21.14

GABS – Gait and balance scale
 PIGD - Postural instability gait dysfunction index
 ABC – Activities specific balance confidence scale

Table 48a: Spearman’s Rho Correlations Performance-Based and Self-Perceived Measures of Balance

	GABS OFF	GABS ON	five step OFF	five step ON	turn left OFF	turn left ON	turn right OFF	turn right ON	PIGD OFF	PIGD ON	ABC
GABS OFF	1.000										
GABS ON	0.862	1.000									
five step OFF	0.435	0.441	1.000								
five step ON	0.374	0.461	0.751	1.000							
turn left OFF	0.658	0.564	0.700	0.445	1.000						
turn left ON	0.537	0.630	0.633	0.619	0.762	1.000					
turn right OFF	0.692	0.555	0.643	0.433	0.860	0.694	1.000				
turn right ON	0.560	0.644	0.650	0.644	0.749	0.939	0.725	1.000			
PIGD index OFF	0.740	0.633	0.264	0.172	0.555	0.344	0.553	0.379	1.000		
PIGD index ON	0.605	0.656	0.236	0.167	0.476	0.441	0.443	0.459	0.794	1.000	
ABC	-0.732	0.626	0.388	-0.349	-0.629	-0.426	0.659	0.474	0.656	-0.432	1.000

GABS – Gait and balance scale

PIGD – Postural instability gait dysfunction index

ABC – Activities specific balance confidence scale

Bold – significant p<.05 with Fisher’s Z transformation

The GABS OFF, turn 360 degrees to right OFF medications and PIGD index OFF medications correlated significantly & negatively with the ABC scale

Table 48b: Significant Correlations between Self-Perceived & Performance Balance Measures

Variables	Spearman's Rho	Fisher's Z	P	95% confidence interval
GABS off & GABS ON	0.862	6.724	0.000	0.794 -0.908
GABS off & turn left off	0.658	2.146	0.032	0.516 -0.765
GABS off & turn right off	0.692	2.705	0.007	0.560 -0.789
GABS off & PIGD off	0.740	3.588	0.000	0.624-0.824
GABS off & ABC	-0.732	3.432	0.001	-0.614 to -0.818
GABS on & PIGD on	0.656	2.115	0.034	0.513-0.763
5 step off & 5 step on	0.751	3.810	0.000	0.639-0.831
5 step off & turn left off	0.700	2.844	0.004	0.571-0.795
5 step off & turn right on	0.650	2.021	0.041	0.506-0.759
Turn left off & turn left on	0.762	4.040	0.000	0.654-0.839
Turn left off & turn right off	0.860	6.655	0.000	0.792-0.907
Turn left off & turn right on	0.749	3.769	0.000	0.637-0.830
Turn left on & turn right off	0.694	2.740	0.000	0.563-0.791
Turn left on & turn right on	0.939	10.556	0.000	0.908-0.960
Turn right off & turn right on	0.725	3.299	0.001	0.604-0.813
Turn right off & ABC	-0.659	2.162	0.031	-0.517 to -0.765
PIGD off & ABC	-0.656	2.115	0.034	-0.513 to -0.763
PIGD off & PIGD on	0.794	4.766	0.000	0.694-0.859

GABS – Gait & balance scale
 ABC – Activities specific balance confidence scale
 PIGD – Postural instability gait dysfunction index
 Turns – 360 degree turns

Correlation between Performance Balance Measures

Several of the performance measures correlated with each other (Table 48b). There were good to excellent correlations between all balance measures ON & OFF PD medications with the strongest being the GABS ($r = 0.862$, 95% confidence interval 0.794 - 0.908), followed by the PIGD index ($r=0.794$, 95% confidence interval 0.694 - 0.859), turn 360 degrees to the left ($r = 0.762$, 95% confidence interval 0.654 - 0.839), the five step test ($r = 0.751$, 95% significance interval 0.639 - 0.831), and finally the 360 degree turn to the right ($r = 0.725$, 95% confidence interval 0.604 - 0.813). There were several significant relationships between the GABS OFF medications, specifically the PIGD OFF medications ($r = 0.740$, 95% confidence interval 0.624 - 0.824), turning 360 degrees to the right ($r = 0.692$, 95% confidence interval 0.560 - 0.789), and finally turning 360 degrees to the left OFF medications ($r = 0.658$, 95% confidence interval 0.516 - 0.765). ON medications the GABS was significantly correlated with the PIGD index ON medications ($r = 0.656$, 95% confidence interval 0.513 - 0.763). The five step OFF medications was significantly related to turning 360 degrees to the left OFF medications ($r = 0.700$, 95% confidence interval 0.571 - 0.795), and turning 360 degrees to the right ON medications ($r = 0.650$, 95% confidence interval 0.506 - 0.759). There were no significant correlations between the five step test ON medications and any other performance balance measure. Turning 360 degrees to the left and turning 360 degrees to the right in the same medications states were strongly related, specifically turning 360 degrees to the left and right OFF medications ($r = 0.860$, 95% confidence interval 0.792 - 0.907), and turning 360 degrees to the left and right ON medications ($r = 0.939$, 95% confidence interval 0.908 - 0.960). Additionally turning 360 degrees to the left OFF medications was significantly related to turning 360 degrees to the right ON medications ($r = 0.749$, 95% confidence interval 0.637- 0.830). Turning 360 degrees to the left ON

medications was associated with turning 360 degrees to the right OFF medications ($r = 0.694$, 95% confidence interval 0.563 - 0.791). The reader is directed to Tables 48a&b for further details.

Summary Results Specific Aim 2

Three performance based measures were significantly & negatively correlated with the self-perceived ABC scale, specifically the GABS OFF medications, the 360 degree turn to the right OFF medications and the PIGD index OFF medications. All balance measures OFF medications correlated highly with their counterpart ON medications. The correlations between turning to the left and right were excellent both ON & OFF PD medications. The GABS OFF medications correlated with the most balance measures besides the ABC scale, specifically the PIGD OFF and turning 360 to the left and right OFF medications. Finally the 5 step test was related to turning 360 degrees in both directions, specifically OFF medications to the left and ON medications to the right.

SPECIFIC AIM 3 was to determine whether instrumented measures of gait variables (velocity, cadence, stride length) on the GAITRite were the same as over ground measures of the same gait parameters, first with the participant walking forward, then walking fast forward, and finally walking backward, both ON & OFF PD medications.

Walking Forward Usual Speed

Alpha was set at 0.05 for all tests walking forward at a usual speed.

Hypothesis 1a was that there would be no significant difference between the means for each gait parameter (velocity, cadence, and stride length) measured walking

forward at a usual speed on the GAITRite and over ground, both ON & OFF PD medications.

Hypothesis 1b was that the estimated Spearman's rho correlations for each gait parameter (velocity, cadence, and stride length), made walking forward at a usual speed on the instrumented GAITRite and over ground, would be > 0.7 , both ON & OFF PD medications.

Velocity:

The descriptive information for velocity for all sites walking forward at a usual speed is presented in Table 49, and has been discussed previously under specific aim 1 hypothesis 3. Table 50 and figure 1 review all paired t-tests for velocity walking forward at a usual speed. Tables 25-28 summarize the correlations between velocity measured walking forward at a usual speed on the GAITRite and over ground. Gait velocity was significantly higher walking on the GAITRite than over ground at all sites ON & OFF PD medications with the exception of Galveston OFF medications ($p = 0.940$), and the combined Galveston VA group again OFF medications ($p = 0.163$). There were no significant correlations for velocity walking forward at a usual speed on the GAITRite and over ground ON & OFF PD medications, with the exception of the VA group 1 and VA Group 2 OFF medications. When reviewing reports in the literature, clinicians should realize that measures of velocity on the GAITRite are higher than those over ground.

Cadence:

Descriptive information for cadence at all sites walking forward at a usual speed is summarized in Table 51, and has been discussed under specific aim 1 hypothesis 3 above. The correlations for cadence walking forward at a usual speed on the GAITRite and over ground in both medications states are presented in Tables 25-28. Table 52 and figure 2 review the results of paired t-tests for cadence walking on the GAITRite and

over ground. Paired t-tests showed that the means for cadence were higher walking on the GAITRite than over ground, both ON & OFF PD medications, with the exception of Galveston OFF medications ($p = 0.06$), and the VA Group 2 ON medications ($p = 0.153$). There were no significant correlations for cadence walking forward at a usual speed on the GAITRite and over ground. Variability around the means for cadence was large, and distributions around the means for cadence measured on the GAITRite and over ground were not the same. Nevertheless, it is important to note that the mean for cadence walking forward at a usual speed was almost the same both ON & OFF PD medications, as well as on the GAITRite and over ground, for the VA Group 2 (figure 2), and the combined Galveston VA group (figure 2). When cadence changed it was higher on the GAITRite than over ground, especially at the VA Group 1 (figure 2). When reading literature on cadence walking forward at a usual speed, clinicians should recognize that cadence, when it changes between the GAITRite and over ground, is higher on the GAITRite. Mean cadence, measured walking forward at a usual speed on the GAITRite and over ground, was not the same.

Stride Length:

The descriptive data for stride length walking forward at usual speed is reviewed in Table 53, and has been discussed previously under specific aim 1 hypothesis 3 above. The results of paired t-tests on stride length walking on the GAITRite and over ground are presented in Table 54 and Figure 3. Tables 25-28 summarize the correlations for stride length walking forward at a usual speed measured on the GAITRite and over ground in both medications states. There was **no** significant difference in mean stride length walking forward at usual speed on the GAITRite and over ground at all sites ON & OFF PD medications. The variability around the means was high. Stride length walking forward at a usual speed on the GAITRite and over ground was significantly

correlated only in the VA Group 2 OFF medications. Clinicians reading the literature should be mindful that while mean stride length measured on the GAITRite and over ground were not significantly different, the variability was too high to conclude that the two measurement techniques were equivalent.

Table 49: Descriptive Statistics Velocity All Sites Walking Forward Usual Speed

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Gal vel GR OFF	76.69	30	26.66	4.87
	Gal vel OG OFF	77.11	30	28.39	5.18
Pair 2	Gal vel GR ON	98.40	28	20.35	3.85
	Gal vel OG ON	85.25	28	17.94	3.39
Pair 3	V1 vel GR OFF	75.99	21	30.65	6.69
	V1 vel OG OFF	67.79	21	25.10	5.48
Pair 4	V1 vel GR ON	91.05	23	21.14	4.41
	V1 vel OG ON	79.38	23	16.87	3.52
Pair 5	V2 vel GR OFF	91.65	37	27.10	4.45
	V2 vel OG OFF	83.92	37	25.07	4.12
Pair 6	V2 vel GR ON	106.71	37	26.53	4.36
	V2 vel OG ON	93.49	37	26.04	4.28
Pair 7	GV2 vel GR OFF	84.95	67	27.73	3.39
	GV2 vel OG OFF	80.87	67	26.62	3.25
Pair 8	GV2 vel GR ON	103.13	65	24.25	3.01
	GV2 vel OG ON	89.94	65	23.11	2.87

Gal – Galveston
V1 – VA Group 1
V2 - VA Group 2
GV2 – Galveston & VA group 2 combined
Vel – velocity
GR – GAITRite
OG – over ground

Table 50: Paired T-tests Velocity All Sites Walking Forward Usual Speed

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Gal vel GR OFF – Gal vel OG OFF	-0.42	30.14	5.50	-11.67	10.83	-0.076	29	0.940
Pair 2	Gal vel GR ON – Gal vel OG ON	13.15	17.59	3.32	6.33	19.97	3.955	27	0.000
Pair 3	V1 vel GR OFF – V1 vel OG OFF	8.19	16.22	3.54	0.81	15.58	2.315	20	0.031
Pair 4	V1 vel GR ON – V1 vel OG ON	11.67	16.43	3.43	4.56	18.77	3.406	22	0.003
Pair 5	V2 vel GR OFF – V2 vel OG OFF	8.14	17.95	2.99	2.06	14.21	2.719	35	0.010
Pair 6	V2 vel GR ON – V2 vel OG ON	14.24	20.39	3.40	7.35	21.14	4.192	35	0.000
Pair 7	GV2 vel GR OFF- GV2 vel OG OFF	4.25	24.44	3.01	-1.76	10.26	1.412	65	0.163
Pair 8	GV2 vel GR ON - GV2 vel OG ON	13.77	19.08	2.38	9.00	18.53	5.773	63	0.000

Gal – Galveston
V1 –VA Group 1
V2 – VA Group 2
GV2 – Galveston & VA Group 2
GR – GAITRite
OG – over ground
Bold significant p<.05

Means for velocity walking forward were significantly higher on the GAITRite than over ground with the exception of Galveston & Galveston VA2 off PD medications

Table 51: Descriptive Statistics Cadence All Sites Walking Forward Usual Speed

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Gal cad GR OFF	103.49	30	18.41	3.36
	Gal cad OG OFF	96.67	30	16.58	3.03
Pair 2	Gal cad GR ON	109.77	28	17.48	3.30
	Gal cad OG ON	93.88	28	21.89	4.14
Pair 3	V1 cad GR OFF	118.54	22	33.98	7.24
	V1 cad OG OFF	95.97	22	17.39	3.70
Pair 4	V1 cad GR ON	117.15	23	28.20	5.88
	V1 cad OG ON	102.12	23	14.92	3.11
Pair 5	V2 cad GR OFF	110.83	36	14.21	2.37
	V2 cad OG OFF	104.88	36	13.13	2.19
Pair 6	V2 cad GR ON	110.33	36	14.55	2.43
	V2 cad OG ON	104.98	36	17.13	2.85
Pair 7	GV2 cad GR OFF	107.50	66	16.54	2.04
	GV2 cad OG OFF	101.15	66	15.25	1.88
Pair 8	GV2 cad GR ON	110.08	64	15.77	1.97
	GV2 cad OG ON	100.12	64	19.98	2.50

Gal – Galveston

V1 – VA Group 1

V2 – VA Group 2

GV2 - Galveston & VA Group 2

Cad – cadence

GR – GAITRite

OG – over ground

Table 52: Paired T-Tests Cadence All Sites Walking Forward Usual Speed

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Gal cad GR OFF – Gal cad OG OFF	6.82	19.11	3.49	-0.31	13.96	1.955	29	0.060
Pair 2	Gal cad GR ON – Gal cad OG ON	15.89	31.06	5.87	3.85	27.94	2.708	27	0.012
Pair 3	V1 cad GR OF - V1 cad OG OFF	22.57	38.74	8.26	5.39	39.75	2.733	21	0.012
Pair 4	V1 cad GR ON - V1 cad OG ON	15.02	27.90	5.82	2.96	27.09	2.582	22	0.017
Pair 5	V2 cad GR OFF - V2 cad OG OFF	5.95	14.58	2.43	1.02	10.89	2.449	35	0.019
Pair 6	V2 cad GR ON - V2 cad OG ON	5.37	21.97	3.66	-2.09	12.78	1.460	35	0.153
Pair 7	GV2 cad GR OFF - GV2 cad OG OFF	6.35	16.66	2.05	2.25	10.44	3.095	65	0.003
Pair 8	GV2 cad GR ON - GV2 cad OG ON	9.96	26.63	3.33	3.31	16.61	2.992	63	0.004

Gal – Galveston
V1 – VA Group 1
V2 – VA Group 2
GV2 - Galveston & VA Group 2
Cad – cadence
GR – GAITRite
OG – over ground
Bold – significant p<.05

Means for cadence were significantly higher walking on the GAITRite than over ground ON & OFF PD medications with the exception of Galveston OFF medications and the VA2 ON medications

Table 53: Descriptive Statistics Stride Length All Sites Walking Forward Usual Speed

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Gal GR SL OFF	93.83	30	29.01	5.30
	Gal OG SL OFF	100.29	30	34.50	6.30
Pair 2	Gal GR SL ON	109.54	28	21.63	4.09
	Gal OG SL ON	109.84	28	28.53	5.39
Pair 3	V1GR SL OFF	78.74	22	24.64	5.25
	V1 OG SL OFF	81.45	22	29.82	6.36
Pair 4	V1 GR SL ON	96.70	23	17.66	3.68
	V1 OG SL ON	94.12	23	21.54	4.49
Pair 5	V2 GR SL OFF	99.94	37	24.85	4.09
	V2 OG SL OFF	95.98	37	22.58	3.71
Pair 6	V2 GR SL ON	113.85	37	26.25	4.32
	V2 OG SL ON	107.09	37	23.32	3.83
Pair 7	GV2 GR SL OFF	97.21	67	26.76	3.27
	GV2 OG SL OFF	97.90	67	28.39	3.47
Pair 8	GV2 GR SL ON	111.99	65	24.28	3.02
	GV2 OG SL ON	108.27	65	25.52	3.17

Gal – Galveston
V1 – VA Group 1
V2 – VA Group 2
GV2 – Galveston & VA Group 2
SL – stride length
GR – GAITRite
OG – over ground

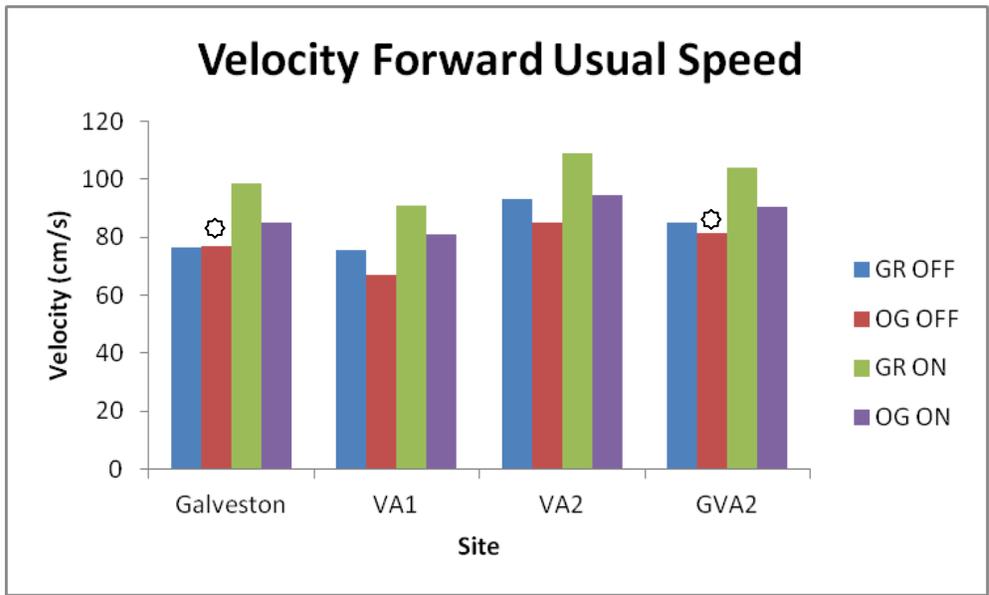
Table 54: Paired T-Tests Stride Length All Sites Walking Forward Usual Speed

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Gal GR SL OFF – Gal OG SL OFF	-6.45	34.54	6.31	-19.35	6.45	-1.023	29	0.315
Pair 2	Gal GR SL ON – Gal OG SL ON	-0.30	23.21	4.39	-9.30	8.70	-0.068	27	0.946
Pair 3	V1 GR SL OFF - V1 OG SL OFF	-2.71	31.54	6.72	-16.70	11.27	-0.403	21	0.691
Pair 4	V1 GR SL ON - V1 OG SL ON	2.58	23.22	4.84	-7.46	12.62	0.532	22	0.600
Pair 5	V2 GR SL OFF - V2 OG SL OFF	3.97	12.39	2.04	-0.16	8.10	1.948	36	0.059
Pair 6	V2 GR SL ON – V2 OG SL ON	6.76	24.99	4.11	-1.57	15.09	1.645	36	0.109
Pair 7	GV2 GR SL OFF - GV2 OG SL OFF	-0.70	25.20	3.08	-6.84	5.45	-0.226	66	0.822
Pair 8	GV2 GR SL ON - GV2 OG SL ON	3.72	24.31	3.02	-2.30	9.74	1.234	64	0.222

Gal – Galveston
V1 – VA Group 1
V2 – VA Group 2
GV2 – Galveston and VA Group 2
SL – stride length
GR – GAITRite
OG – over ground
Bold – significant p < 0.05

The means for stride length measured on the GAITRite and over ground were not significantly different at all sites ON & OFF PD medications

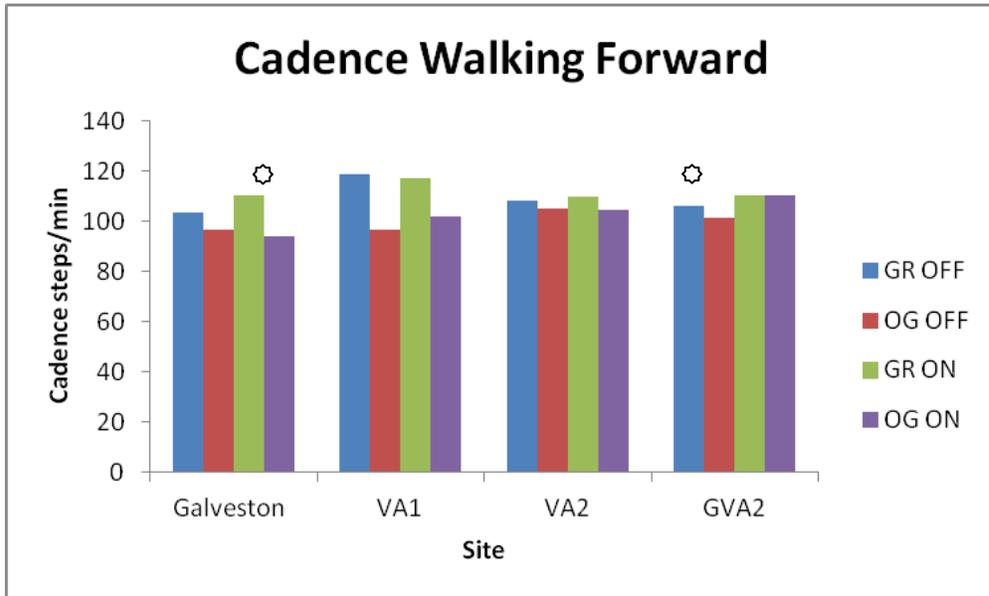
Figure 1: Velocity Walking Forward GAITRite vs. Over Ground and ON vs. OFF PD Medications



⊛ Means not significantly different $p > 0.05$

Means for velocity were significantly higher on the GAITRite than over ground walking forward at a usual speed at all sites ON medications and at the VA Groups 1&2 OFF medications

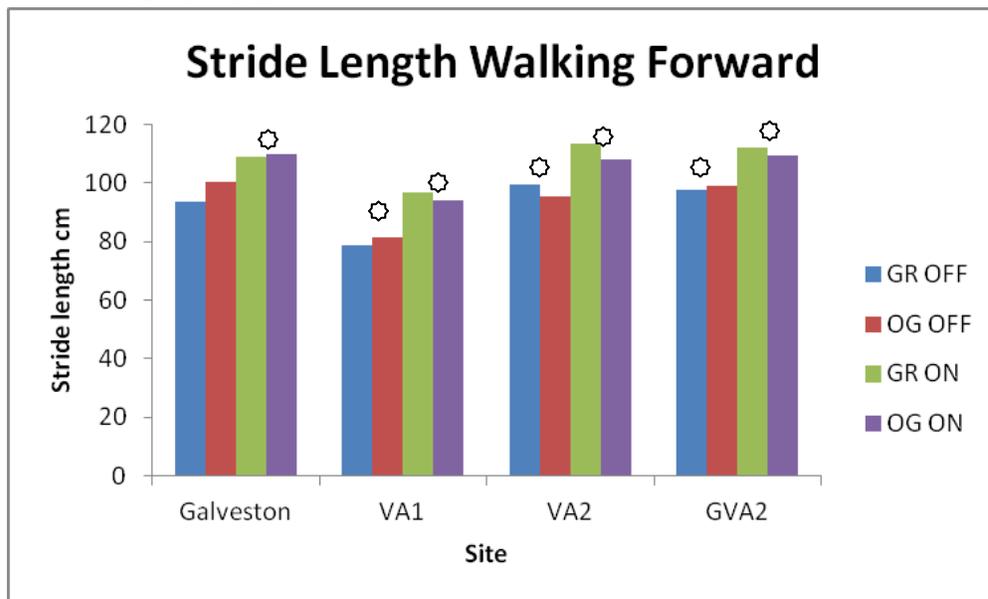
Figure 2: Cadence Walking Forward GAITRite vs. Over Ground and ON vs. OFF PD Medications



⊛ Means for cadence were not significantly different $p > 0.05$

Cadence did not change much on GAITRite and over ground and ON & OFF PD medications especially in the VA Group 2 and in the combined Galveston VA Group 2

Figure 3: Stride Length Walking Forward GAITRite vs. Over Ground ON vs. OFF PD Medications



⊗ Means not significantly different $p > 0.05$

Means measured on the GAITRite and over ground were not significantly Different regardless of medications state

Walking Forward at a Fast Speed

Alpha was set at 0.05 for all tests of fast walking.

Hypothesis 2a was that there would be no significant difference between the means for each gait parameter (velocity, cadence, and stride length) measured walking forward at a fast speed on the GAITRite and over ground, both ON & OFF PD medications.

Hypothesis 2b was that the estimated Spearman rho correlations for gait parameters (velocity, cadence, and stride length), made walking forward at a fast speed on the instrumented GAITRite and over ground, would be >0.7 , both ON & OFF PD medications.

Unfortunately the available data only allowed comparison of velocity walking fast forward ON & OFF PD medications. Table 55 summarizes the descriptive data for all sites walking forward at a fast pace ON & OFF PD medications. Tables 30-35 summarize correlation coefficients for walking forward at a fast speed on the GAITRite and over ground for both medication states. Table 56 and figure 4 show the results of paired t-tests comparing walking fast forward on the GAITRite and over ground. Mean velocity measured walking on the GAITRite was significantly faster than mean velocity measured over ground at all sites ON medications, and at all sites OFF medications with the exception of Galveston ($r = 0.78$). There were significant correlations between walking fast forward on the GAITRite and over ground at all sites ON medications and at the VA Group 1 and combined Galveston VA group OFF medications. The means represent a single point in a distribution and can be significantly different even when the correlations that represent the distributions are the same. Given the large number of correlations between walking fast forward on the GAITRite and over ground, further research with a larger group is needed to determine whether measurements made for velocity walking fast forward on the GAITRite and over ground are the same.

Table 55: Descriptive Statistics Velocity All Sites Walking Fast Forward

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Gal fvel GR OFF	127.80	29	34.87	6.48
	Gal fvel OG OFF	115.89	29	42.36	7.87
Pair 2	Gal fvel GR ON	145.00	28	31.28	5.91
	Gal fvel OG ON	128.84	28	34.77	6.57
Pair 3	V1 fvel GR OFF	117.03	22	40.86	8.71
	V1 fvel OG OFF	92.91	22	30.70	6.54
Pair 4	V1 fvel GR ON	135.08	23	35.00	7.30
	V1 fvel OG ON	115.50	23	28.47	5.94
Pair 5	V2 fvel GR OFF	140.90	36	37.68	6.28
	V2 fvel OG OFF	122.65	36	35.52	5.92
Pair 6	V2 fvel GR ON	146.53	36	33.70	5.62
	V2 fvel OG ON	131.74	36	36.79	6.13
Pair 7	GV2 fvel GR OFF	135.05	65	36.76	4.56
	GV2 fvel OG OFF	119.63	65	38.56	4.78
Pair 8	GV2 fvel GR ON	145.86	64	32.41	4.05
	GV2 fvel OG ON	130.47	64	35.67	4.46

Gal – Galveston
V1 – VA Group 1
V2 – VA Group 2
GV2 – Galveston & VA Group 2
Fvel – fast velocity
GR – GAITRite
OG – over ground

Table 56: Paired T-Tests Velocity All Sites Walking Fast Forward

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Gal fvel GR OFF – Gal fvel OG OFF	11.91	35.09	6.52	-1.44	25.26	1.828	28	0.078
Pair 2	Gal fvel GR ON – Gal fvel OG ON	16.17	24.69	4.67	6.59	25.74	3.465	27	0.002
Pair 3	V1 fvel GR OFF - V1 fvel OG OFF	24.12	29.146	6.21	11.20	37.04	3.882	21	0.001
Pair 4	V1 fvel GR ON - V1 fvel OG ON	19.58	26.686	5.56	8.04	31.12	3.519	22	0.002
Pair 5	V2 fvel GR OFF - V2 fvel OG OFF	18.24	24.99	4.16	9.79	26.70	4.381	35	0.000
Pair 6	V2 fvel GR ON - V2 fvel OG ON	14.79	25.86	4.31	6.04	23.53	3.431	35	0.002
Pair 7	GV2 fvel GR OFF - GV2 fvel OG OFF	15.42	29.84	3.70	8.02	22.81	4.166	64	0.000
Pair 8	GV2 fvel GR ON - GV2 fvel OG ON	15.39	25.16	3.15	9.10	21.67	4.893	63	0.000

Gal – Galveston
V1 – VA Group 1
V2 – VA Group 2
GV2 – Galveston & VA Group 2
Fvel – fast velocity
GR – GAITRite
OG – over ground
Bold – significant p<.05

The means for measuring velocity walking fast forward were not significantly different measured on the GAITRite and over ground except in Galveston OFF medications

Walking Backward

Alpha was set at 0.05 for all tests walking backward.

Hypothesis 3a was that there would be no significant difference between the means for each gait parameter (velocity, cadence, and stride length), measured walking backward at a safe speed on the GAITRite and over ground, both ON & OFF PD medications.

Hypothesis 3b was that the estimated Spearman rho correlations for the gait parameters (velocity, cadence, and stride length), made walking backward at a safe speed on the instrumented GAITRite and over ground, would be >0.7 , both ON & OFF PD medications.

Velocity

The means and standard deviations for velocity walking backward at all sites on the GAITRite and over ground are reviewed in Table 57, and have been discussed under specific aim 1 hypothesis 3 above. Table 58 and figure 5 summarize the results of paired sample t-tests for walking on the GAITRite and over ground. Tables 35-38 describe the correlations for velocity walking backward on the GAITRite and over ground in both medications states. There was **no** significant difference in measures for mean velocity calculated walking backward on the GAITRite and walking backward over ground both ON & OFF PD medications, with the exception of the combined Galveston VA2 group ON medications ($p = 0.28$). Velocity measured walking backward on the GAITRite and over ground was significantly correlated in Galveston, and in the combined Galveston VA group OFF medications, and in Galveston ON medications. It is premature to conclude that measurements for velocity measured on the GAITRite and over ground are equivalent. The clinician should note that many patients with PD cannot increase their

velocity significantly walking backward OFF medications or ON medications, but when they can, the means tend to be higher over ground than on the GAITRite.

Table 57: Descriptive Statistics Velocity All Sites Walking Backward

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Gal bvel GR OFF	50.23	23	27.12	5.65
	Gal bvel OG OFF	54.79	23	28.91	6.03
Pair 2	Gal bvel GR ON	62.17	22	20.16	4.30
	Gal bvel OG ON	67.08	22	27.10	5.78
Pair 3	V1 bvel GR OFF	38.03	12	22.78	6.58
	V1 bvel OG OFF	35.36	12	14.66	4.23
Pair 4	V1 bvel GR ON	49.62	13	22.98	6.37
	V1 bvel OG ON	44.14	13	14.93	4.14
Pair 5	V2 bvel GR OFF	65.24	34	32.84	5.63
	V2 bvel OG OFF	67.06	34	26.98	4.63
Pair 6	V2 bvel GR ON	70.40	35	29.66	5.01
	V2 bvel OG ON	78.74	35	34.15	5.77
Pair 7	GV2 bvel GR OFF	59.19	57	31.30	4.15
	GV2 bvel OG OFF	62.110	57	28.18	3.73
Pair 8	GV2 bvel GR ON	67.22	57	26.51	3.51
	GV2 bvel OG ON	74.24	57	31.88	4.22

Gal – Galveston
V1 – VA Group 1
V2 – VA Group 2
Bvel – backward velocity
GR – GAITRite
OG – over ground

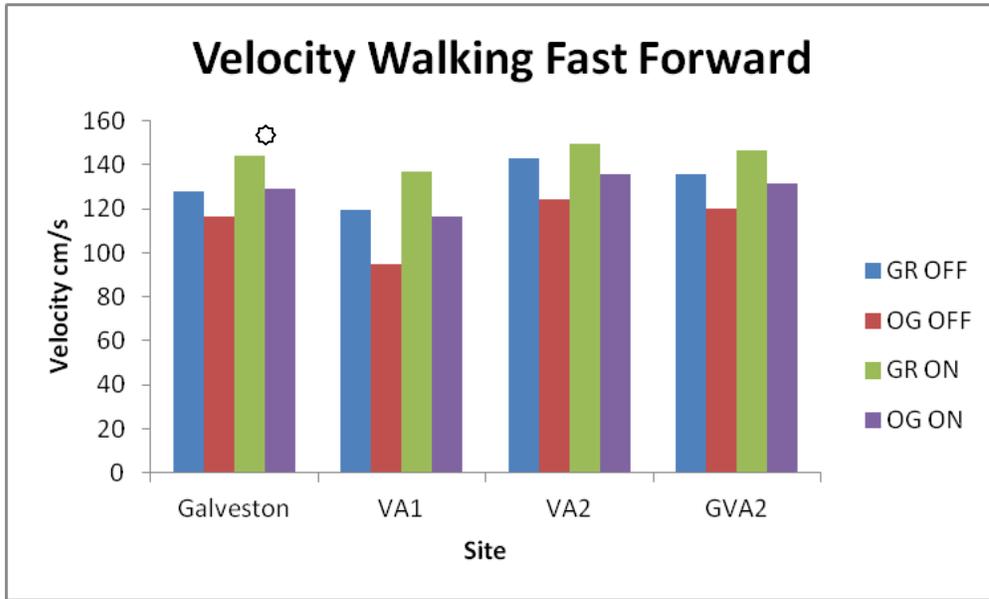
Table 58: Paired T-Test Velocity All Sites Walking Backward

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Gal bvel GR OFF – Gal bvel OG OFF	-4.56	22.73	4.74	-14.39	5.27	-0.962	22	0.347
Pair 2	Gal bvel GR ON – Gal bvel OG ON	-4.90	17.53	3.74	-12.68	2.87	-1.312	21	0.204
Pair 3	V1 bvel GR OFF - V1 bvel OG OFF	2.68	23.92	6.91	-12.52	17.87	0.387	11	0.706
Pair 4	V1 bvel GR ON - V1 bvel OG ON	5.48	27.80	7.71	-11.31	22.28	0.711	12	0.490
Pair 5	V2 bvel GR OFF - V2 bvel OG OFF	-1.81	32.91	5.64	-13.30	9.67	-0.321	33	0.750
Pair 6	V2 bvel GR ON - V2 bvel OG ON	-8.34	26.69	4.51	-17.51	0.83	-1.849	34	0.073
Pair 7	GV2 bvel GR OFF - GV2 bvel OG OFF	-2.92	29.04	3.85	-10.63	4.78	-0.760	56	0.451
Pair 8	GV2 bvel GR ON - GV2 bvel OG ON	-7.02	23.47	3.11	-13.24	-0.79	-2.257	56	0.028

Gal – Galveston
V1 – VA Group 1
V2 – VA Group 2
GV2 - Galveston & VA Group 2
Bvel – backward velocity
GR – GAITRite
OG – over ground
Bold – significant p <.05

There was no significant difference in the means for velocity walking backward measured over ground and on GAITRite at all sites with the exception of the Galveston VA2 combined group ON medications

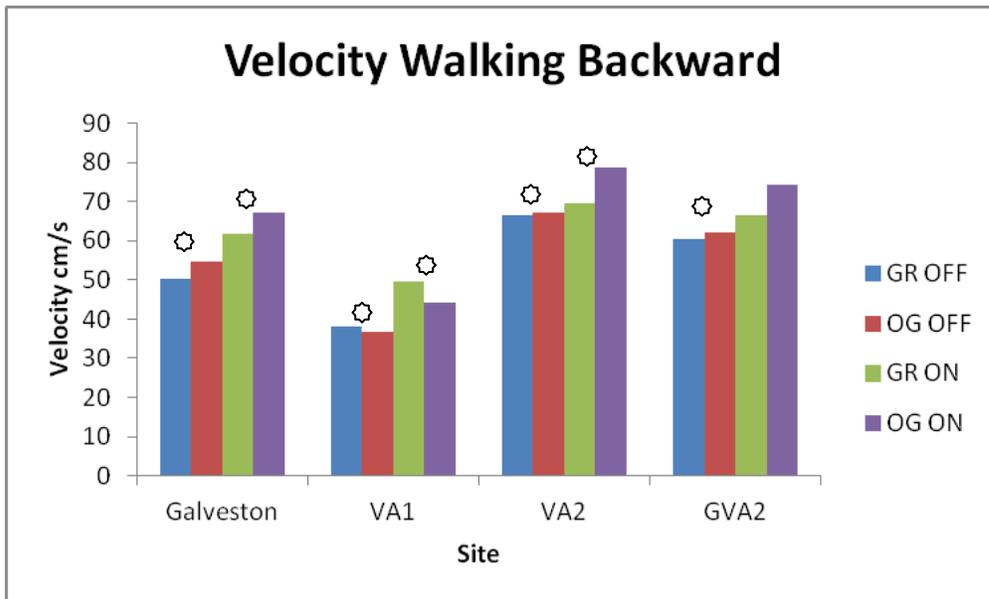
Figure 4: Velocity Walking Fast Forward GAITRite vs. Over Ground OFF vs. ON Medications



* Means were not significantly different $p > 0.05$

Mean for velocity walking fast forward on the GAITRite were significantly higher walking over ground ON & OFF PD medications

Figure 5: Velocity Walking Backward GAITRite vs. Over Ground OFF vs. ON Medications



* Means were not significantly different $p > 0.05$

All measures of the mean for velocity walking backward on GAITRite and over ground were not significantly different with the exception the combined group ON medications

Cadence:

The descriptive data for measures of cadence walking backward at all sites under both medication conditions is summarized in table 59, and has been discussed in specific aim 1 hypothesis 3 above. Table 60 and figure 6 review results of paired t-tests for cadence measured walking backward over ground and on GAITRite. Tables 35-38 summarize the correlations for cadence walking backward on the GAITRite and over ground both ON & OFF PD medications. The means for cadence were significantly higher over ground than on the GAITRite at all sites with the exception of the VA group 1 OFF medications ($p=0.999$), and ON medications ($p=0.370$). The VA Group 1 used the GAITRite software version 3.3 that could not be exported to the newer software version for analysis. Additionally the size of the group was very small. Mean cadence was significantly higher over ground than on the GAITRite, ON & OFF PD medications. There were no significant correlations between cadence walking backward on the GAITRite and over ground, regardless of medications state. When reviewing the literature the clinician should keep in mind that mean cadence is higher walking backward over ground. There is no evidence to support that measurements for cadence made walking backward on the GAITRite and over ground are the same.

Stride Length:

The descriptive data for stride length walking backward on the GAITRite and over ground at all sites is summarized in Table 61; details of this data have been presented under specific aim 1 hypothesis 3 above. Paired t-tests results between stride length walking backward on the GAITRite and over ground are reviewed in Table 62 and figure 7. Correlations between stride length measured on the GAITRite and over ground in both medications states are presented in Tables 35-38. Stride length was significantly higher measured walking backward on the GAITRite than over ground at all sites OFF

medications with the exception of the VA Group 1. There was no significant difference in the means for stride length measured walking backward on the GAITRite and over ground at all sites, with the exception of the combined Galveston VA2 group ON medications. There were several significant correlations for stride length measured walking backward on the GAITRite and over ground, specifically in Galveston ON medications, at the VA2 ON & OFF PD medications, and at the combined Galveston VA2 group ON & OFF PD medications. With the large number of significant correlations for stride length measured on the GAITRite and over ground, further studies with larger samples are needed to investigate whether measurements for stride length walking backward on the GAITRite and over ground are the same. Clinicians should remember that OFF medications the mean for stride length is higher measured on the GAITRite. Table 63 summarizes the paired T-test and Spearman's rho correlations for all of the gait parameters walking backward ON & OFF PD medications.

Summary Specific Aim 3

The results varied depending on the gait parameter, and the direction or speed of walking. Walking forward the mean for velocity was significantly higher walking on the GAITRite than over ground at all sites ON medications, and at the VA1 and VA2 OFF medications. However there was no evidence that the distributions around the two means for velocity were similar. Walking fast forward the mean for velocity was significantly higher on the GAITRite than over ground both ON & OFF PD medications with the exception of Galveston OFF medications. There were several instances when correlations for velocity walking fast forward on the GAITRite and over ground were significant, even though the means were significantly different. Walking backward, there was no significant difference between the means for velocity walking on the GAITRite and over

ground ON & OFF PD medications, with the exception of the combined Galveston VA group OFF medications. The distributions around the means for velocity walking backward on the GAITRite and over ground were similar for Galveston, and the combined Galveston VA2 group OFF medications, and at Galveston ON medications. Further studies with larger samples are needed to determine whether measures for velocity walking forward on the GAITRite and over ground OFF medications are congruent. Presently one cannot conclude that measurements for velocity made walking on the GAITRite and over ground are equivalent regardless of medications state, speed or direction of walking. Cadence walking forward, was higher on the GAITRite than over ground OFF medications at all sites with the exception of Galveston, and ON medications at all sites with the exception of the VA Group 2., Walking backward cadence was significantly higher walking over ground than on the GAITRite both ON & OFF PD medications with the exception of the VA Group 1. There was no evidence to support that the distributions around the two means for cadence were equivalent regardless of walking direction. Therefore, one cannot conclude that measurements for cadence made on the GAITRite an over ground were the same, both walking forward and backward. The mean for stride length was not significantly different measured walking forward on the GAITRite and over ground at all sites, both ON of OFF PD medications. However distributions around the means for stride length walking forward at a usual speed were not equivalent, with the exception of the VA Group 2 OFF medications. Stride length was significantly higher walking backward on the GAITRite than over ground in Galveston, at the VA Group 2 and in the combined group OFF medications, and in the combined Galveston VA2 group ON medications. The correlations for stride length walking backward on the GAITRite and over ground were statistically significant in Galveston ON PD medications, at the VA Group 2 ON & OFF PD medications, and at the combined

GVA2 group in both medication states. The distributions around the means for stride length walking backward on the GAITRite and over ground were the same, even when the means were significantly different walking backward. While some of the measures for stride length were equivalent measured on the GAITRite and over ground, either OFF or ON medications, or in both states, it is premature to conclude that measures for stride length made on the GAITRite and over ground walking forward and/or backward are the same. Further research with larger samples is needed.

Table 59: Descriptive Statistics Cadence All Sites Walking Backward

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Gal bcad GR OFF	102.93	23	38.82	8.09
	Gal bcad OG OFF	117.95	23	28.06	5.85
Pair 2	Gal bcad GR ON	108.36	22	23.11	4.93
	Gal bcad OG ON	124.56	22	23.31	4.97
Pair 3	V1 bcad GR OFF	111.88	12	41.14	11.88
	V1 bcad OG OFF	111.91	12	22.70	6.55
Pair 4	V1 bcad GR ON	106.16	13	29.50	8.18
	V1 bcad OG ON	117.41	13	29.58	8.20
Pair 5	V2 bcad GR OFF	113.34	34	30.49	5.23
	V2 bcad OG OFF	139.41	34	33.02	5.66
Pair 6	V2 bcad GR ON	114.78	35	28.47	4.81
	V2 bcad OG ON	130.91	35	35.67	6.03
Pair 7	GV2 bcad GR OFF	109.14	57	34.15	4.52
	GV2 bcad OG OFF	130.75	57	32.63	4.32
Pair 8	GV2 bcad GR ON	112.30	57	26.50	3.51
	GV2 bcad OG ON	128.46	57	31.40	4.16

Gal – Galveston
V1 – VA Group 1
V2 – VA Group 2
GV2 - Galveston & VA Group 2
bcad – backward cadence
GR – GAITRite
OG – over ground

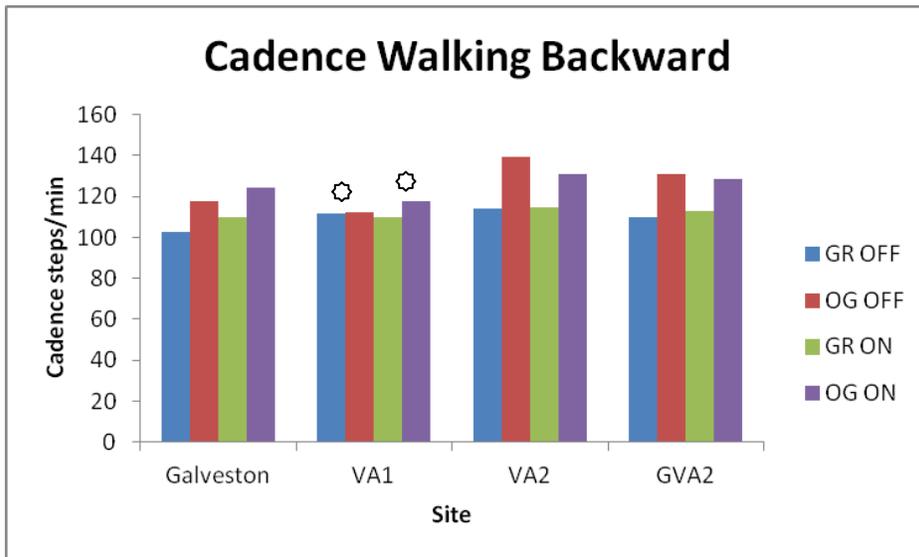
Table 60: Paired T-Tests Cadence All Sites Walking Backward

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Gal bcad GR OFF – Gal bcad OG OFF	-15.01	32.84	6.85	-29.21	-0.81	-2.193	22	0.039
Pair 2	Gal bcad GR ON – Gal bcad OG ON	-16.20	24.75	5.28	-27.18	-5.23	-3.071	21	0.006
Pair 3	V1 bcad GR OFF - V1 bcad OG OFF	-0.03	53.47	15.43	-34.00	33.95	-0.002	11	0.999
Pair 4	V1 bcad GR ON - V1 bcad OG ON	-11.25	43.55	12.08	-37.57	15.06	-0.932	12	0.370
Pair 5	V2 bcad GR OFF - V2 bcad OG OFF	-26.07	35.85	6.15	-38.57	-13.56	-4.239	33	0.000
Pair 6	V2 bcad GR ON - V2 bcad OG ON	-16.13	34.12	5.77	-27.86	-4.41	-2.797	34	0.008
Pair 7	GV2 bcad GR OFF - GV2 bcad OG OFF	-21.61	34.80	4.61	-30.84	-12.37	-4.688	56	0.000
Pair 8	GV2 bcad GR ON - GV2 bcad OG ON	-16.16	30.60	4.05	-24.28	-8.04	-3.987	56	0.000

Gal – Galveston
V1 – VA Group 1
V2 – VA Group 2
GV2 - Galveston & VA Group 2
bcad – backward cadence
GR – GAITRite
OG – over ground
Bold –significant p<.05

The mean for cadence walking backward was significantly higher walking over ground than on the GAITRite ON & OFF PD medications at all sites with the exception of the VA Group 1. It should be pointed out that the VA1 group was small and used the GAITRite version 3.3.

Figure 6: Cadence Walking Backward GAITRite vs. Over Ground ON vs. OFF PD Medications



Means not significantly different $p > 0.05$

Mean cadence was significantly higher over ground than on the GAITRite both ON & OFF PD medications with the exception of the VA Group 1

Table 61: Descriptive Statistics Stride Length All Sites Walking Backward

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Gal bSL GR OFF	59.21	23	24.88	5.19
	Gal bSL OG OFF	52.95	23	22.89	4.77
Pair 2	Gal bSL GR ON	70.46	22	23.05	4.92
	Gal bSL OG ON	66.07	22	28.42	6.06
Pair 3	V1 bSL GR OFF	42.41	12	24.20	6.99
	V1 bSL OG OFF	31.88	12	16.40	4.74
Pair 4	V1 bSL GR ON	55.95	13	23.97	6.65
	V1 bSL OG ON	48.21	13	19.55	5.42
Pair 5	V2 bSL GR OFF	69.43	34	27.45	4.71
	V2 bSL OG OFF	57.90	34	22.93	3.93
Pair 6	V2 bSL GR ON	74.25	34	24.66	4.23
	V2 bSL OG ON	68.63	34	31.23	5.36
Pair 7	GV2 bSL GR OFF	63.38	51	26.10	3.66
	GV2 bSL OG OFF	55.09	51	21.46	3.00
Pair 8	GV2 bSL GR ON	72.80	50	24.11	3.41
	GV2 bSL OG ON	66.85	50	29.86	4.22

Gal – Galveston
V1 – VA Group 1
V2 – VA Group 2
GV2 – Galveston & VA Group 2
bSL – backward stride length
GR – GAITRite
OG – over ground

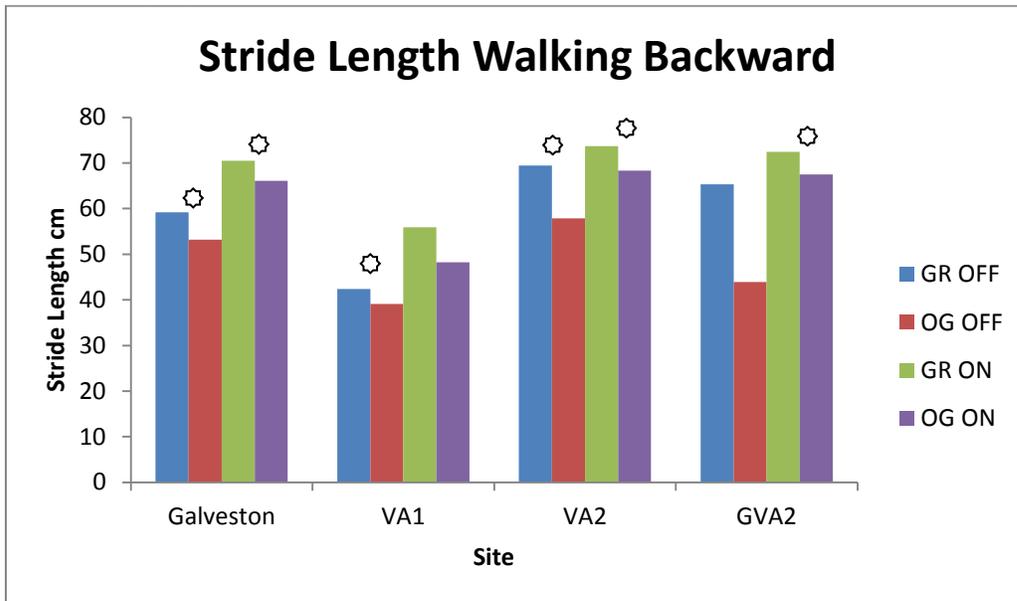
Table 62: Paired T-Tests Stride Length All Sites Walking Backward

		Paired Differences				t	df	Sig. (2-tailed)	
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower				Upper
Pair 1	Gal bSL GR OFF – Gal bSL OG OFF	35.99	31.61	6.59	22.32	49.66	5.461	22	0.000
Pair 2	Gal bSL GR ON – Gal bSL OG ON	4.38	13.64	2.91	-1.67	10.43	1.506	21	0.147
Pair 3	V1 bSL GR OFF - V1 bSL OG OFF	3.30	28.14	8.12	-14.58	21.18	0.407	11	0.692
Pair 4	V1 bSL GR ON - V1 bSL OG ON	7.70	34.10	9.46	-12.90	28.31	0.815	12	0.431
Pair 5	V2 bSL GR OFF - V2 bSL OG OFF	11.53	21.99	3.77	3.86	19.20	3.058	33	0.004
Pair 6	V2 bSL GR ON - V2 bSL OG ON	5.36	20.09	3.40	-1.54	12.26	1.579	34	0.124
Pair 7	GV2 bSL GR OFF – GV2 bSL OG OFF	21.40	28.71	3.80	13.79	29.02	5.629	56	0.000
Pair 8	GV2 bS GR ON – GV2 bSL OG ON	4.98	17.75	2.35	0.27	9.69	2.119	56	0.039

Gal – Galveston
V1 – VA Group 1
V2 – VA Group 2
GV2 – Galveston & VA Group 2
bSL – backward stride length
GR – GAITRite
OG – over ground
Bold – p<.05

Stride length was higher on the GAITRite in Galveston OFF, VA2 OFF, and the combined GVA2 group ON & OFF PD

Figure 7: Stride Length Walking Backward GAITRite vs. Over Ground ON vs. OFF PD Medications



* Means not significantly different $p > 0.05$

Means for stride length walking backward were not significantly different measured on GAITRite and over ground for all sites OFF medications with the exception of the combined Galveston VA2 group, and exclusively at the VA Group 1 ON medications

Table 63: Summary of T-Tests and Correlations between Walking on the GAITRite and Over Ground

Gait variable	T-tests OFF	T-tests ON	Correlations OFF	Correlations ON
Forward velocity	Significantly higher on GAITRite at both VA groups	Significantly higher on GAITRite all sites	Only significant correlation was at the VA Group 1	No significant correlations at all sites
Forward cadence	Significantly higher on GAITRite at all sites except Galveston	Significantly higher on GAITRite at all sites except the VA Group 2	No significant correlations	No significant correlations at all sites
Forward stride length	No significant difference at all sites	No significant difference at all sites	Only significant correlation was at the VA group 2	No significant correlations at all sites
Fast forward velocity	Significantly higher on GAITRite at all sites except Galveston	Significantly higher at all sites on GAITRite at all sites	Significant correlations in the VA group 1 & combined GVA2 group	Significant correlations at all sites
Backward velocity	No significant difference at all sites	No significant difference at all sites except VA Group 1	No significant correlations at all sites	No significant correlation at all sites
Backward cadence	Significantly higher over ground at all sites except VA Group 1	Significantly higher over ground at all sites except VA Group 1	No significant correlations at all sites	No significant correlations at all sites
Backward stride length	Significantly higher on GAITRite except GVA2	No significant difference at all sites except GVA2	Significant correlations in the VA Group 2 & GVA2	Significant correlations at all sites except VA Group 1

VA- Veteran's Administration Group
GVA2 –Galveston VA Group 2

Table 64: Key Findings

Specific Aim	Finding
Specific Aim 1	<ol style="list-style-type: none"> 1. The PIGD index OFF medications was the only performance balance test that correlated with the UPDRS total score OFF medications. 2. None of the balance measures were significantly correlated with the motor section of the UPDRS OFF or ON medications. 3. None of the gait variables were significantly correlated with the UPDRS total score OFF or ON medications. 4. None of the gait variables were significantly correlated with the UPDRS motor section score OFF or ON medications. 5. There were significant correlations between several gait variables ON & OFF PD medications- stride length walking forward and backward and velocity walking fast forward both on the GAITRite and over ground. 6. There were significant correlations between several gait variables walking on the GAITRite and over ground – velocity walking forward, velocity walking fast forward, velocity walking backward & stride length walking forward OFF medications and velocity walking forward, and stride length walking backward ON medications.
Specific Aim 2	<ol style="list-style-type: none"> 1. The PIGD index OFF, GABS OFF and turn R OFF were the performance balance measures that were significantly correlated with the ABC scale. 2. All performance balance measures were significantly correlated ON & OFF PD medications. 3. The GABS OFF medications correlated with the ABC, the PIGD index OFF, and turn 360 degrees to the left and right OFF medications. 4. The 5 step off medications correlated with turning 360 degrees to the left OFF and the right ON medications. 5. There were strong correlations between turning to the left and right ON & OFF PD medications.
Specific Aim 3	<ol style="list-style-type: none"> 1. We cannot conclude that velocity, stride length and cadence measured walking on the GAITRite and over ground are equivalent. 2. Walking forward at a usual speed mean velocity and cadence were higher on the GAITRite than over ground; stride length was not significantly different; there were limited (no more than 1) or no significant correlations between walking on the GAITRite and over ground ON & OFF PD medications. 3. Walking fast forward the mean for velocity was significantly higher on the GAITRite than over ground, but walking on the GAITRite and over ground were significantly correlated at all sites ON medications and at the VA Group 1 and combined Galveston-VA group OFF medications. 4. Walking backward mean velocity was not significantly different, and cadence was higher over ground ON & OFF PD medications, but there were no significant correlations walking on the GAITRite and over ground ON & OFF PD medications. 5. Walking backward mean stride length was significantly higher on the GAITRite OFF medications and not significantly different ON medications; there were significant correlations between walking on the GAITRite and over ground at all sites except the VA Group 1 ON medications and at the VA Group 2 and the combined Galveston VA2 group OFF medications. 6. Further research is needed walking fast forward and backward to examine whether measurements for velocity and stride length are the same walking on the GAITRite and over ground.

Chapter 5 DISCUSSION

This is the first study that examined such a large number of balance and gait measures in patients with Parkinson's disease, both ON & OFF PD medications. Additionally this study targeted patients with PD who were recruited to test two innovative exercise interventions to prevent falls; therefore, the sample had many more patients with moderate disease severity (H&Y stages 2.5-4) than previous studies where most patients had mild disease. This study showed that for the most part, the balance and gait measures utilized, measured constructs different than those of the UPDRS and its motor section.

Scores on all balance and gait measures showed improved performance from the OFF to the ON medication state. Measuring the patient ON & OFF PD medications allows one to see how the patient performs in the worst to best state, over the course of a medication cycle. Foreman and colleagues found that the Functional Gait Assessment (FGA) in the OFF medications state was more accurate (less false-positives and false negatives) for predicting fall history than the ON medications state (Foreman et al. 2011). Valkovic and co-workers found increased area under the receiver operated characteristic curve (a measure of test accuracy) during OFF versus ON medication state for the pull test and the push and release tests (Valkovic et al. 2008).

SPECIFIC AIM 1

Hypothesis 1: Performance on the Balance Measures

The first hypothesis considered how measures of balance correlated with the UPDRS total score. This section will summarize how the study participants performed on each of the balance tests and compare their performance to those of other patients with

PD in the literature. The mean and standard deviation for the UPDRS total score for our participants OFF medications was 44.38 ± 16.8 , and ON medications was 33.43 ± 13.34 . This difference in scores between the ON & OFF PD medications states suggests that the UPDRS is sensitive to dopaminergic medications. It is well known that both tremor and rigidity are improved with dopamine, therefore, due to their high weighting on the UPDRS, the improvement in total scores is reasonable (Adkin et al. 2003). Scores for the UPDRS OFF medication in the current study were higher than the mean and standard deviation for the ON medication scores reported by Schenkman 39.21 ± 2.93 (Schenkman et al. 2011) and Tanji 42.9 ± 19.8 (Tanji et al, 2008), as would be expected. Moreover the ON medication scores for our study were much lower than those reported by Schenkman and Tanji. Forty four percent of the subjects in the Schenkman study had mild disease, while the remaining 56% had moderate disease, like most of our participants (Schenkman et al. 2011). The H&Y stages for the subjects in the Tanji study ranged from 1-5, with 60% classified as stage 2 and 13% as stage 3. His subjects had less severe disease than the individuals in our study (Tanji et al. 2008). There are 3 possible explanations for why the subjects in our study performed better than those of Schenkman and Tanji ON medications. First, more of our participants may have been taking dopamine, and the favorable response to the medication may have resulted in improved UPDRS scores. Second, our participants performed their ON medication testing 1 hour after ingestion of dopamine, and were known to be at peak dose; it is unclear where the subjects in the Schenkman and Tanji studies were in the medication cycle, and whether they were truly at peak dose. Alternatively, our subjects may have shown a learning effect performing better on the second test (ON medications) than the first (OFF medications).

The mean and standard deviation scores on the Gait and Balance Scale (GABS) were 29.72 ± 15.11 OFF medications, and 21.57 ± 12.91 ON medications. The GABS appears to be sensitive to dopaminergic medications, since lower scores indicate better performance. The GABS scores in this study were higher OFF medications than those of Thomas and colleagues, where the mean score OFF medications was 26.4. ON medications scores on the GABS in this study were lower than those of Thomas and colleagues, where the mean was 23.4 (Thomas et al. 2004). The Thomas study included 35 participants, Hoehn & Yahr (H&Y) stages 1-3, however there was no breakdown of how many individuals were in each stage. The inclusion of subjects H&Y stage 1 meant that the subjects in the Thomas study might have had less severe disease than the participants in this study. This would explain why her group scored better than our group OFF medications, the indicator of true disease state. That our participants scored lower than those of Thomas ON medications might be explained by the fact that with more disease severity more of our subjects were using dopaminergic medications and were having a favorable response to the drug. Alternatively higher functioning subjects have less room to improve even with the medications.

The mean and standard deviation scores on the 5 step test were 14.66 ± 6.65 OFF medications, and was 11.52 ± 3.66 ON medications. There were no other studies that could be located that utilized the 5 step test as an outcome measure for persons with PD in the reviewed literature, thus no comparisons could be made. In a study of 12 insulin-resistant elderly persons who were receiving protein supplementation, their baseline time (mean and standard deviation) for the 5 step test was 8.77 ± 0.78 seconds and they improved in the 16 weeks of the study to 7.71 ± 0.60 seconds. As can be seen these individuals performed much faster than our subjects, even ON PD medications. Another study was carried out first, to identify which physical performance measures

differentiated able from disabled community-dwelling elderly individuals, and second, to determine the cut off scores for each test that had the best diagnostic ability, specifically that had the highest sensitivity and specificity (Wang et al. 2005). Two hundred and three community dwelling elderly, mean age 74 (range 60-91), 76.8% female, 32% Caucasian, 38% African American, and 33% Hispanic were recruited. Within this cohort 27.3% had heart disease and 26.9% had diabetes. Twenty three percent used a cane for mobility and 5% used a walker for mobility. Participants were classified into 3 groups based on their response to 2 questions- first can you walk several blocks, and second, can you climb stairs? Those who responded yes to both questions were assigned to the able group; those who responded yes to 1 of the 2 questions were classified as decreasing, and those who responded no to both questions were placed in the disabled group. Approximately 44% of the participants had fallen at least once, however the time span for fall data collection was not reported. Participants performed 5 physical performance tests – walk for 5 minutes, 5 step test, 50 foot walk (15 meters), functional reach, and stand to floor to stand transfer. Mean and standard deviation for age in the able group was 72.6 ± 6.8 , increased to 75.5 ± 7.0 for the decreasing group, and increased again to 78.8 ± 6.6 years old in the disabled group. Mean and standard deviation score on the 5 step test was 0.37 ± 0.10 steps/second in the able group, 0.24 ± 0.11 steps/second in the decreasing group and 0.17 ± 0.1 steps/second in the disabled group. The 5 step test was significantly correlated with the functional reach ($r = 0.60$, $p < 0.01$), 50 foot walk ($r = 0.79$, $p < 0.01$), and 5 minute walk ($r = 0.72$, $p < 0.01$) using Kendall's tau (Wang et al. 2005). The cutoff value for the 5 step test that differentiated between the able and decreasing groups was 0.26 steps/second, yielding sensitivity of 60.5% and specificity of 85.4%. The cutoff value for the 5 step test that differentiated between the decreasing and disabled groups was 0.15 steps/second, yielding sensitivity of 47.1% and specificity of 90.7% (Wang et al. 2005).

In our study participants were younger, 2/3 male, and more homogeneous in race predominantly Caucasian. Our participants had a higher prevalence of cardiac disease and a lower prevalence of diabetes. They were more likely to have fallen in the past year, were equivalent in the use of a cane, and finally, were much more likely to use a walker. OFF medications our participants had a mean score of 0.34 steps/second for the 5 step test, and ON medications had a mean score of 0.43 steps/second. Thus, our participants with PD performed better than the community dwelling able group ON medications, and almost the same as the able group OFF medications. One possible explanation for this might be that we excluded potential participants if they had a neurological or musculoskeletal condition that interfered with walking, or if they could not walk a minimum of 5 meters independently. The only inclusion criteria for the Wang and associates study were age greater than 60, community dwelling and able to follow directions (Wang et al. 2005). They had no walking requirement in their inclusion criteria, thus they may have had more individuals with neurological or musculoskeletal conditions that interfered with walking than we did. In fact 5.5% of the subjects in the study by Wang and colleagues could not walk across a room (Wang et al. 2005).

The mean and standard deviation time to turn 360 degrees to the left OFF medications was 6.86 ± 11.37 seconds, and to the right was 7.36 ± 12.39 seconds. ON medications, the mean and standard deviation time to turn 360 degrees to the left was 4.80 ± 5.76 seconds, and to the right was 5.50 ± 11.98 seconds. Thus, there was approximately 2 seconds difference between turning 360 degrees ON & OFF PD medications. The times to turn 360 degrees in this study are in agreement with Schenkman's findings that patients with PD in H&Y stage 2 ON medications typically take (mean and standard deviation) 3.91 ± 1.37 seconds to turn 360 degrees at their best and 7.35 ± 1.96 seconds at their worst. At their best, again ON medications, patients in

H&Y stage 2.5 take (mean and standard deviation) 4.81 ± 1.58 seconds to turn 360 degrees and at their worst 8.66 ± 2.66 seconds. Finally persons with PD at H&Y stage 3 ON medications take (mean and standard deviation) 7.34 ± 3.60 seconds to turn 360 degrees at their best and 11.04 ± 3.61 seconds at their worst (Schenkman et al. 2011).

The mean and standard deviation score for the postural instability gait dysfunction (PIGD) index in the current study was 6.83 ± 3.21 OFF medications, and 5.32 ± 2.79 ON medications. A discriminant factor analysis performed on the UPDRS, identified a factor that related to axial mobility, balance, and gait (Stebbins 1998). Items that loaded on this factor were: item 13- number of falls, item 14- freezing when walking, item 28- posture, item 29- gait and item 30- postural stability. These 5 items were described as the postural instability gait dysfunction index of the UPDRS. These 5 items, each scored on a scale of 0-4 with higher scores representing greater disease severity, made up the PIGD index, which has a maximum score of 20 (Stebbins et al. 1998). This is the PIGD index that was used in this study. When researchers began to use the motor section of the UPDRS for disease severity classification, a new PIGD index based on the motor section of the UPDRS emerged. It was based on factor 1 of the motor section of the UPDRS, axial function, balance, and gait. The items that loaded on it were items 27-30 of the motor section of the UPDRS: item 27- rising to standing from a standard height chair, item 28- posture, item 29- gait and item 30- postural stability/retropulsion (Stebbins et al. 2001). There are only 4 items on factor 1 of the motor section, each scored on a scale of 0-4, for a maximum of 16 points for the motor PIGD. (Stebbins et al. 2001). The argument for using the motor section of the UPDRS and the 4 item PIGD is that it is entirely performance based. The older UPDRS PIGD includes items from the ADL section of the UPDRS which are scored by patient or caregiver report, in addition to the performance based motor section items. The self-reported items refer to falls and freezing of gait.

While there is evidence for “amnesia of falls” or under-reporting of falls, the scoring choices for item 13 of the UPDRS make forgetting a few falls irrelevant (Bloem et al. 2001). The patient or caregiver simply needs to think whether he/she falls less than, equal to, or more than once a day. Similarly for UPDRS item 14 freezing when walking, the patient or caregiver needs to decide whether freezing has resulted in any, a single, or multiple falls. With better understanding of freezing of gait, and new measures to quantify freezing of gait, the older PIGD index is being replaced by the objective motor one (Salarian et al. 2009; Franzen et al. 2011). Nevertheless there are 3 items that overlap between the two PIGD indices – posture, gait, and postural instability (retropulsion). In a study of 15 patients with mild to moderate PD (7 in H&Y stage 2, 4 in stage 2.5, and 4 in stage 3), the mean motor PIGD index OFF medications was 4 (range 1-7) and ON medications was 2.5 (range 1-5) (Franzen et al. 2011). In a study of 12 patients with PD not yet taking dopaminergic medications, and in H&Y stages 1-2.5, 7 subjects had PIGD scores of 0, 3 had scores of 1, and 1 each had PIGD motor scores of 2 & 3. The PIGD index from the UPDRS motor section (items 27-30) was used as a clinical measure of mobility and balance since there was no item for turning on the UPDRS. The authors concluded that the PIGD motor index did not appear to be sensitive to early, mild disease (Salarian et al. 2009).

Considering the Activities Specific Balance Confidence scale (ABC), the mean and standard deviation score for persons in this study was 67.9 ± 21.24 %. Mak suggested 3 categories for scoring the ABC - high, moderate and low. Persons with PD, who score over 80% on the ABC scale, are in the high category and are not at risk for falling. Individuals with PD with scores between 50% and 80% on the ABC, are classified in the moderate category, where fall risk begins. Scores below 50% on the ABC are classified in the low category, where fear of falling may be so high that individuals begin to limit

activities, and avoid tasks which they perceive as dangerous (Mak et al. 2009a). The score that separated those at risk for falling and those not at risk for falling in persons with PD was 69% (Mak et al. 2009b). The ABC score in the current study is below the 69% cutoff for falls risk proposed by Mak and colleagues. The authors concluded that fear of falling was independently associated with actual falls over a 1 year period (Mak et al. 2009b). This coincided with the fact that we recruited subjects with postural instability for the current study. Indeed there were many participants who had a history of recurrent falls (2 or more in a 12 month period).

Hypothesis 1: Correlations of the Balance Measures with the UPDRS

The first hypothesis was to determine whether any of the balance measures utilized in the current study were significantly related to the UPDRS total score. The PIGD index was the only balance measure that correlated significantly with the UPDRS, but only in the OFF medications state ($r = 0.710$, 95% confidence interval 0.584- 0.802). There were no balance measures that were significantly correlated with the UPDRS total score ON PD medications. Additionally step wise regression analysis showed that the PIGD OFF medications and the ABC scale predicted 44.4% of the variability in UPDRS scores OFF medications. After patients took their PD medications, the GABS ON medications and the PIGD index ON medications predicted 35.8% of the variance in UPDRS scores.

That the PIGD index OFF medications correlated with the UPDRS total score OFF medications might be explained simply because the items are derived from the UPDRS. It may also be that falling, freezing, stooped posture, shuffling small step gait, and postural instability are the result of the tremor, rigidity, and/or bradykinesia so well represented on the total UPDRS score. The relationship of the PIGD index OFF

medications to the UPDRS OFF medications is further supported by the regression analysis, where the PIGD index OFF medications and the ABC explained 44.4% of the variability in UPDRS scores OFF medications. In a study comparing patients with PD who fell with patients with PD who did not fall, Mak found that fallers had lower scores on the ABC scale than non-fallers (Mak et al. 2009b). In a 1 year prospective study Mak and Pang identified 70 patients with PD, 55 who had fallen one time or less, and 15 who had fallen more than once. Stepwise discriminant factor analysis was used to try to differentiate single from recurrent fallers. The first step consisted of entering and comparing age, female gender, positive fall history, depression scale scores, disease duration, disease severity (measured by H&Y scale scores), UPDRS motor scores, TUG scores and ABC scale scores. Step 1 showed that history of a previous fall was the most important factor in predicting patients with PD who fall recurrently ($F = 32.57$, $p < 0.001$). After controlling for history of a previous fall (step 2), the UPDRS motor score ($F = 25.23$, $p < 0.001$) and ABC scale score ($F = 18.84$, $p < 0.001$) still predicted patients with PD with recurrent falls. After controlling for history of a previous fall, UPDRS motor section score, and ABC scale score, age, female gender, depression state, disease duration, disease severity, or TUG scores no longer contributed to differentiating single from recurrent fallers. The final model, history of a previous fall, low ABC scale scores and high UPDRS motor section scores had an accuracy of 87% for predicting patients with PD who would fall recurrently, with a sensitivity of 93%, and a specificity of 86%. The authors concluded that patients with PD with history of a previous fall, high scores on the UPDRS motor section, and low scores on the ABC scale were at risk for recurrent falls (Mak et al. 2009a). Receiver operated characteristic curves were created in order to determine the cutoff score for the ABC scale, and UPDRS motor section, which yielded the highest sensitivity and specificity for identifying patients with PD with who would

fall recurrently (Mak et al. 2009a). For the ABC scale, a cutoff score of 69 resulted in a sensitivity of 0.93 and a specificity of 0.67. For the UPDRS motor section, a cutoff score of 32 provided a sensitivity of 0.47 and a specificity of 0.94. The authors concluded that when used together the ABC scale and the UPDRS motor scores yielded a sensitivity of 0.93 and a specificity of 0.94; this combined test sensitivity and specificity is better than each of the individual test scores in predicting patients with PD who would fall recurrently (Mak et al. 2009a). A final study compared 72 patients with PD to 74 healthy controls to differentiate physical function, falls frequency, and falls circumstances (Mak et al. 2010). Demographic data collected included age, gender, height, weight, use of an assistive device, Minnesota Leisure Time Activity Questionnaire score, Geriatric Depression Scale score, and mini mental status examination scores; additional data collected for subjects with PD included H&Y stage, UPDRS total score, pull test (item 29 UPDRS), dose of carbidopa-levodopa, and PIGD phenotype (ratio of mean of UPDRS items 20-21, tremor and action tremor, to mean of UPDRS items 27-30, rise to stand posture gait and postural stability). If the ratio was less than 1, the individual had the postural instability gait dysfunction phenotype. All participants performed 5 performance-based tests: 6 minute walk test, gait velocity on the GAITRite, 5 time sit to stand, TUG, and standing on 1 leg; additionally they completed the self-report ABC scale. The participants were then followed for a year to determine number of falls and their circumstances. Participants were classified as non-fallers if they had no falls in the follow up period, single fallers if they experienced one fall in the year of follow up, and recurrent fallers if they fell more than 1 time in follow up. None of the physical performance measures were significantly different between the PD non-faller (n=47) and PD single faller groups (n=12). However comparing non-fallers, single and recurrent fallers, recurrent fallers (n=13) walked 24% less in the 6 minute walk test, showed 20%

slower gait velocity, took 38% more time to transfer sit to stand 5 times, and took 34% more time to perform the TUG (Mak et al. 2010). Factors that differentiated PD recurrent fallers from non-fallers, included H&Y stage, history of previous fall, UPDRS motor score, and dose of carbidopa-levodopa. Factors that differentiated single and recurrent fallers included history of falls, number of falls in the 12 month follow-up, and UPDRS motor score (Mak et al. 2010). There was no significant difference in PIGD phenotype across groups, where 89.4% of non-fallers had the PIGD phenotype and 100% of fallers had the phenotype. Similarly there was no significant difference on the pull test between groups. Recurrent fallers had significantly lower ABC scale scores than single fallers and non-faller PD and control participants ($p < 0.05$). Thus a high UPDRS motor score, a performance measure, and a low ABC scale score, a self-report measure, were characteristic of recurrent fallers (Mak et al. 2010). Both types of measure are needed in evaluation and in the development of a physical therapy plan of care.

Very few of the existing balance measures have been tested in the OFF medications state. There are many balance measures that have been shown to correlate with the UPDRS when tested in the ON medications state. The BBS correlated negatively with the UPDRS with correlations ranging from -0.64 to -0.76 (Brusse et al. 2005; Tanji et al. 2008; Leddy et al. 2011a; King et al. 2012). The TUG correlated positively with the UPDRS with correlations ranging from 0.67- 0.75 (Brusse et al. 2005; Lim et al. 2005). Brusse showed that the FRT was negatively correlated with the UPDRS ($r = -0.69$, $p < 0.001$) (Brusse et al. 2005). On the other hand, the FRT in the backward direction was not significantly related to the UPDRS (Lim et al. 2005). Transferring from sitting to standing consecutively was significantly correlated with the UPDRS ($r = 0.565$, $p = .001$) and the UPDRS motor section ($r = 0.563$, $p < 0.002$) (Song et al. 2009). The BESTest correlated significantly with the MDS-UPDRS ($r = -0.758$ $p < 0.001$) (Leddy et al.

2011b). The FGA correlated significantly with the MDS-UPDRS ($r = 0.692$, $p < 0.001$) (Leddy et al. 2011a). The ABC correlated significantly with the MDS-UPDRS ($r = -0.523$, $p < 0.01$) (Leddy et al. 2011b). When Leddy correlated the BESTest to the UPDRS and the MDS-UPDRS, the correlations were higher for the MDS-UPDRS (Leddy et al. 2011b). What made these evaluation tools correlate with the UPDRS while the 360 degree turn, 5 step test, and GABS did not? While the BBS, FRT, and TUG have all been used in patients with PD, they were originally designed to measure falls risk in community dwelling elderly (Berg et al. 1989; Richardson et al. 1989; Duncan et al. 1990; Berg et al. 1992). The majority of items on the BBS and the FRT measure static balance where the center of body mass (COBM) moves over a fixed base of support (BOS). Conversely, dynamic balance is required both for the 5 step test and the 360 degree turn tests. Dynamic balance is challenged when the COBM moves over a changing BOS. Perhaps the UPDRS measures static balance more than dynamic balance. Since the BBS does not have any items on gait, perhaps the UPDRS does not measure gait skills as much as balance skills. It should be noted that persons with PD fall most frequently when walking, so the UPDRS might fall short on measuring the influence of gait (Mak et al. 2010). Tanji suggested that the first 10 items on the BBS are different than the last 4 items, stating that the first 10 items are more representative of H&Y stages 2.5- 3 (moderate disease severity), while items 11- 14 characterize the person with PD in H&Y stage 2 (mild disease severity) (Tanji et al. 2008). Possibly the UPDRS is more sensitive to patients with PD with moderate disease severity, where postural instability begins. This is supported by Schenkman's finding the UPDRS is not able to detect change in the person with mild disease (Schenkman et al. 2011). Schenkman also recommended that the BBS and FRT be used as examination measures in later disease severity (Schenkman et al. 2011). Despite the correlation of the BBS with the UPDRS,

there are problems using it in Parkinson's disease. The BBS has ceiling effects, and the recommended cutoff for greatest sensitivity (52) is close to the maximal score (56) (Dibble 2008; Tanji et al. 2008). The TUG also correlated with the UPDRS. Schenkman reported that the TUG could detect change throughout the continuum of mild to moderate PD, however the change in scores from H&Y stage 1 to H&Y stage 3 was only 2.5 seconds (Schenkman et al. 2011). Minimal detectable change for the TUG is 5 seconds, less than the span between individuals with mild to moderate PD (Steffen et al. 2008). The TUG is difficult to interpret in persons with PD because it contains so many items that provoke freezing, which can add seconds to the score. Persons with PD might have start hesitation, slow down while turning 180 degrees, experience start hesitation again after the turn, and freeze upon arrival at the chair all factors that could inflate the timed score even though postural stability might not be deficient (Morris et al. 2001; Huang et al. 2008; Foreman et al. 2010). Schenkman found that the FRT also declined steadily with the progression of PD, but that the difference in the best and worst participants in her study was only 2 inches (Schenkman et al. 2011). Interestingly the FRT backward did not correlate significantly with the UPDRS (Lim et al. 2005). One possible explanation for this is that persons with PD have such reduced limits of stability posteriorly (Horak et al. 2005).

Despite the fact that the GABS contains the FRT, TUG, 4 items from the UPDRS and 7 items from the BBS, it did not correlate significantly with the UPDRS in either medication state in the current study (Thomas et al. 2004). This might be because the GABS includes so many items on gait, which is less well represented on the UPDRS than balance. The GABS contains the entire performance orientated mobility analysis (POMA) gait section, which examines step initiation, step height and width, degree to which one leg passes the other, step continuity, path deviation and heel to heel support

(Kegelmeyer et al. 2007). Additionally the GABS requires participants to walk on heels, on toes and in tandem. Despite the fact that the GABS did not correlate with the UPDRS OFF medications, the GABS did correlate with the PIGD when both were measured OFF medications. The PIGD is the postural instability gait dysfunction factor of the UPDRS that only contains a single item on walking (Stebbins et al. 1998). This further supports the suggestion that the UPDRS might be measuring more components of balance than walking.

In this study, the ABC scale did not significantly correlate with the UPDRS in either medications state. A single study by Leddy found that the ABC correlated with the MDS-UPDRS ($r = -0.523$) (Leddy et al. 2011a). The MDS-UPDRS is scored differently than the UPDRS, specifically it adds scoring the non-motor symptoms with the 0-4 scale, and quantifies the extent to which tremor interferes with function (Goetz et al. 2008). This might make it more responsive than the older UPDRS. Nevertheless like the GABS, 10 of the 16 items on the ABC scale were directly related to confidence in balance while walking (Powell et al. 1995). The ABC's emphasis on walking not balance is opposite to that of the UPDRS. A person who lacks balance confidence during a particular task may score well performing that test, if they have already modified their behavior to minimize the risk (Rogers et al. 2005). There are 5 to 6 items on the ABC scale that provoke lack of balance confidence more than the others: stand on a chair and reach, stand on tip toes to reach, walk in a crowded mall and be bumped, ride the escalator with and without handrails and walk on an icy sidewalk (Peretz et al. 2006; Oude Nijhuis et al. 2007; Lohnes et al. 2010). Predictive skills are needed when walking in an open changing environment like the mall, and when stepping ON & OFF PD an escalator (Horak et al. 1996; Shumway-Cook et al. 1997; Horak et al. 2005). Standing on a chair to reach, and standing on tiptoes, both require the individual to balance when proprioceptive input is

reduced, and require complex balance skills probably beyond those of the UPDRS (Horak et al. 1996; Shumway-Cook et al. 1997; Horak et al. 2005).

How do the timed 5 step and 360 degree turn tests differ from the UPDRS? Both are dynamic measures of balance where the COBM moves over a changing BOS. Both are repetitive sequences of movements usually controlled at an automatic level, something that is problematic for individuals with PD (Schenkman et al. 2000). Persons performing the 5 step test must be able to perform a series of steps in sequence namely: shift the weight laterally onto one leg, lift a foot up onto the step, climb the step, transfer the body weight up to and over the elevated stance foot, lift the second leg from the ground behind onto the step (with limited visual input), change directions abruptly, lower one leg backward off the step (without visual cues), lower the body from the step, and finally transfer the body weight backward onto the stance leg behind (again with limited visual input). Moreover the person is standing on one leg while lifting or lowering the body weight. These skills are much more challenging than simply standing on one leg, or placing alternate feet repetitively onto a step like in the BBS (Berg et al. 1992). A person performing the 360 degree turn must also perform, a series of skills sequentially namely: shift the weight laterally onto one leg, step sideways and backward with the free leg simultaneously rotating the pelvis forward over the stance leg, shift the weight onto the new stance leg simultaneously rotating the pelvis back and loading the leg, step forward and inward with the new free leg, dissociate segments of the trunk, and dissociate neck from trunk pelvis and legs. The person is loading the leg while rotating the head and torso over a single stance limb. If the typical speed for a healthy community dwelling elderly person to turn 360 degrees is ≤ 4 seconds to each side and ≤ 8 steps for the two sides, the rate of turning is two steps per second (Berg et al. 1992). This means that the individual is turning approximately 45 degrees per step. The faster the person turns, the fewer the

steps needed to complete the turn, the wider the turning angle, and the greater the postural challenge (Huxham et al. 2008a). Franzen showed that individuals with PD had greater tone than healthy control subjects in the neck (75%), trunk (22%), and hips (32%). Additionally, the results suggested that increased neck tone might contribute to limitations in functional mobility, balance, walking, and turning due to the inadequate dissociation of the head and neck from the trunk and pelvis (Franzen et al. 2009). There is evidence that tone is not responsive to dopamine medications, and that the resistive torque to neck, trunk and hip rotation is no different ON & OFF PD medications (Franzen et al. 2009). There was no significant relationship between the resistive tone at the neck, trunk, or hips, and the UPDRS motor section score, the UPDRS item 22 on rigidity, the item on neck rigidity within item 22, and the posture item 28 on the UPDRS (Franzen et al. 2009). It may be that the 360 degree turn requires more trunk rotation than that required to perform all of the tasks on the UPDRS. There was no correlation between the neck rigidity item on the UPDRS and functional performance tasks like balance, turning, and walking (Franzen et al. 2009). Even though the 360 degree turn is a component of the BBS, scoring uses an ordinal scale which is based on whether the subject can make a 360 degree turn in 4 seconds or less to one, or both sides (Berg K, Wood-Dauphinee S, et al. 1992). Exact times are neither recorded nor considered in the score. Additionally, the BBS score is derived from the total score on the 14 items, and the 360 degree turn is not singled out. Conversely, in the current study, we scored the 360 degree turn as a separate test using two continuous measures, time in seconds and number of steps to turn. Huxham reported that persons with PD, compared to healthy age-matched controls, not only take longer to turn, but also take more steps to complete the turn and have reduced stride length during and after the turn (Huxham et al. 2008 a&b). The difference in

measurement precision might explain why the BBS correlated with the UPDRS whereas our 360 degree turn measure did not.

Hypothesis 2: Performance on Balance Measures & UPDRS Motor Section

Hypothesis 2 was to determine whether any of the balance measures used in the current study significantly correlated with the UPDRS motor section. The scores for each of the balance measures have been presented under hypothesis 1 above and will not be repeated. The mean and standard deviation score on the UPDRS motor section in this study was 27.32 ± 11.66 OFF medications, and 18.62 ± 8.76 ON medications. These scores are similar to those of persons with a falls history in a study by Foreman and colleagues, (mean H&Y stage OFF medications of 3 and ON medications of 2.5), where mean and standard deviation of the UPDRS motor section score was 27.29 ± 7.96 OFF medications, and 17.00 ± 8.07 ON medications. Persons in the Foreman study above who did not have a falls history (mean H&Y stage OFF medications of 2.5 and ON medications of 2.25), had mean and standard deviation scores on the motor section of the UPDRS of 25.36 ± 9.99 OFF medications, and 11.57 ± 6.43 ON medications (Foreman et al. 2011). Our scores are also similar to those of Bryant, whose sample consisted of 30 subjects, H&Y stage 2.58 ± 0.42 ON medications, where mean and standard deviation scores on the motor section of the UPDRS were 29.12 ± 11.36 OFF medications and 18.39 ± 8.55 ON medications (Bryant et al. 2011). Finally our scores were higher than those of Brusse and associates, who tested 25 individuals with PD, mean H&Y stage 2, and found that the mean and standard deviation for the UPDRS motor section score was 14 ± 7 ON PD medications. The subjects in that study had less severe disease and thus scored better on the motor section of the UPDRS (Brusse et al. 2005).

Hypothesis 2: Correlations of the Balance Measures with the UPDRS Motor Section:

None of the balance measures examined in the current study (GABS, timed turning 360 degrees, 5 step test, PIGD index) were significantly correlated with the motor section of the UPDRS, either OFF or ON PD medications. A study by Brusse and colleagues reported that the UPDRS motor section correlated significantly with the BBS ($r = -0.69$), the forward FRT ($r = -0.45$), and TUG ($r = 0.58$) (Brusse et al. 2005). The authors suggested an overlap in construct, specifically upright postural control, between the UPDRS and the BBS. Furthermore the authors explained the correlation between the UPDRS motor section and the TUG since there was an overlap of rise to standing and walking on both tests (Brusse et al. 2005).

Hypothesis 3: Performance of Gait Measures and UPDRS Total Score

Walking Forward at a Usual Speed: Velocity

Velocity over ground will be considered first since, in the majority of the other studies, participants walked over ground and ON PD medications. The mean and standard deviation of velocity walking over ground at a usual/comfortable speed ON medications, ranged from a low of 80 ± 15.49 centimeters/second at the VA Group 1, to a high of 94.66 ± 25.40 centimeters/second the VA Group 2, with speeds of 85.25 ± 17.94 centimeters/second in Galveston, and 90.55 ± 22.77 centimeters/second in the combined Galveston VA Group 2 in between. Brusse and colleagues examined 23 subjects with PD, mean H&Y stage of 2, and found that the mean and standard deviation for walking speed over 10 meters, was 91 ± 21 centimeters/second recording from the middle 6 meters of the walkway (Brusse et al. 2005). This velocity is right between those at the VA Group 2 and the combined Galveston VA Group 2, but lower than Galveston and the VA Group 1. The differences between the Brusse study and ours are first, that his

subjects had slightly lower disease severity, H&Y stage 2 compared with our patients with H&Y stage 2.5; second his subjects walked over 6 meters compared with 5 meters in our study; and third he measured the middle 6 meters of the walkway, allowing time for warm up to maximum speed before recording, and stopping recording before deceleration began. Bryant and colleagues examined 30 patients with PD, mean H&Y stage 2.45 ± 0.32 , who walked along a 5 meter walkway, allowing a few steps before and after the walkway for acceleration and deceleration. The mean and standard deviation for velocity for her group was 86.81 ± 22.77 centimeters/second, almost identical to our Galveston group, slightly lower than the VA Group 2 and the combined Galveston VA Group 2, and higher than the VA Group 1. The VA Group 1 had longer disease duration than the other groups in our study, and this might explain why the velocity is lower than that of Bryant and colleagues (Bryant et al. 2012). Steffen and colleagues evaluated 37 patients with PD, mean H&Y stage 2 (13 H&Y stage 1, 7 H&Y stage 2, 9 H&Y stage 3, 8 H&Y stage 4), who walked along a 6 meter walkway, and reported a mean and standard deviation for velocity of 116 ± 34 centimeters/second. This velocity is higher than that of our study, however again their participants had less disease severity, as evidenced by the large number of subjects with mild disease (Steffen et al. 2008). Finally, Song and colleagues recruited 30 subjects with PD, who were within 3 years of diagnosis and without motor fluctuations, with a mean H&Y stage of 1.9. He recorded their walking along a 50 foot (15 meter) walkway allowing a 5 foot (1.25 meter) warm up and cool down area at each end. Their subjects walked at a velocity of 123 centimeters/second, much faster than that of our participants. However, the subjects in the Song study walked a significantly longer distance, were measured only in the middle of a 50 feet walkway, and had lower disease duration and disease severity.

Walking forward over ground at a usual speed OFF medications, our subjects walked at speeds (mean and standard deviation) ranging from a low of 67.05 ± 28.85 centimeters/second at the VA Group 1, to a high speed of 85.29 ± 23.96 centimeters/second at the VA Group 2, with Galveston and the combined Galveston VA Group 2 walking at 77.11 ± 28.39 centimeters/second and 81.58 ± 26.19 centimeters/second respectively. Subjects in the Bryant and colleagues study referred to above, walked at a mean velocity OFF medications of 82.47 ± 24.29 centimeters/second, which is lower than our VA Group 2, similar to the combined Galveston VA Group 2, but higher than the other groups in our study (Bryant et al. 2011). Bryant and colleagues performed a second study to determine whether there was a significant difference between walking ON & OFF PD medications. She recruited 21 subjects, median H&Y stage 2.57, who were all taking levodopa. Their mean and standard deviation for velocity walking OFF medications was 84.14 ± 24.39 centimeters/second, very similar to our VA Group 2, but lower than our other groups (Bryant et al. 2012). It may be that Bryant's subjects who were all on levodopa, may have had greater disease severity than ours where some individuals did not need levodopa.

Walking on the GAITRite ON medications, our subjects walked at a velocity (mean and standard deviation) of 98.49 ± 20.81 centimeters/second in Galveston, 90.92 ± 21.35 centimeters/second at the VA Group 1, 108.91 ± 23.23 centimeters/second at the VA Group 2, and 104.17 ± 22.61 centimeters/second in the combined Galveston VA Group 2 participants. The only other study that examined walking on the GAITRite ON & OFF PD medications, was the first study by Bryant and colleagues. ON medications, their participants walked at a mean and standard deviation for velocity of 98.55 ± 20.90 centimeters/second, which is similar to our Galveston subjects, and lower than our VA2 and combined Galveston VA Group 2 subjects (Bryant et al. 2012). Our participants, like

those of Bryant and colleagues walked faster on the GAITRite than over ground, both ON & OFF PD medications (Bryant et al. 2012).

Walking on the GAITRite OFF medications, our subjects walked at a velocity (mean and standard deviation) of 76 ± 26.66 centimeters/second in Galveston, 75.79 ± 30.79 centimeters/second at the VA Group 1, 93.43 ± 25.19 centimeters/second at the VA Group 2, and 85.82 ± 27.01 centimeters/second for the combined group. Again referring to the study by Bryant and colleagues, their subjects walked at gait velocity (mean and standard deviation) of 86.79 ± 25.44 centimeters/second, a speed similar to our combined group, but higher than our Galveston and VA Group 1 participants (Bryant et al. 2012).

Walking Forward at a Usual Speed – Cadence

Cadence, walking forward over ground at a usual speed ON medications, ranged from a low (mean and standard deviation) of 93.88 ± 21.89 steps/minute in Galveston to a high of 104.45 ± 17.09 steps/minute at the VA Group 2, with the combined group and the VA Group 1 in between at 100.32 ± 20.08 steps/minute and 102.12 ± 14.92 steps/minute, respectively. These cadences are equivalent to Bryant's 30 participants (mean H&Y stage 2.45), where cadence (mean and standard deviation) was 102.76 ± 12.22 steps/minute ON medications (Bryant et al. 2012). On the other hand in a report by Hackney and colleagues, cadence (mean and standard deviation) was 109 ± 1.4 steps/minute walking over ground for 78 persons with PD ON medications, and was 105 ± 1.4 steps/minute walking over ground for 50 healthy age-matched control subjects. This is higher than the cadence in the current study, however 60 of their 78 subjects had mild disease (Hackney et al. 2009). OFF medications walking over ground, cadence in our study ranged from a low (mean and standard deviation) of 96.0 ± 16.99 steps/minute at the VA group 1, to a high of 104.88 ± 13.13 steps/minute at the VA Group 2, with the combined Galveston VA Group2 and Galveston having cadences of 101.15 ± 15.25

steps/minute and 96.67 ± 16.58 steps/minute respectively. These cadences are slightly lower than those of participants in a study by Bryant and colleagues, where cadence (mean and standard deviation) walking over ground OFF medications was 106.43 ± 11.34 steps/minute (Bryant et al. 2012). There was little meaningful change in cadence from the OFF to the ON medication state in our groups. This is in agreement with the limited change in cadence with medication state in the report by Bryant and colleagues (Bryant et al. 2012). It would appear that cadence is not sensitive to dopaminergic medications.

Mean and standard deviation for cadence, walking forward at a usual speed on the GAITRite ON medications, was 110 steps/minute at 3 of the 4 sites in this study. The exception was the VA Group 1, where cadence (mean and standard deviation) was 117.15 ± 28.20 steps/minute. Our cadence is in agreement with that of Bryant and colleagues, where cadence was 111.69 ± 12.12 steps/minute walking forward at a usual speed on the GAITRite ON medications (Bryant et al. 2012). Finally walking forward on the GAITRite at usual speed OFF medications, the range for cadence in our participants was wider. The highest cadence (mean and standard deviation) was 118.54 ± 33.98 steps/minute at the VA Group 1, and the lowest cadence at Galveston was 103.49 ± 18.41 steps/minute. Cadence for the VA Group 2 was 108.05 ± 21.85 steps/minute, and cadence for the combined group was 105.98 ± 20.34 steps/minute. In the study by Bryant and colleagues referred to above, cadence walking forward on the GAITRite OFF medications, was 108.35 ± 12.83 steps/minute (mean and standard deviation), in the middle of the range for cadence under similar conditions in the current study (Bryant et al. 2012).

Walking Forward at Usual Speed – Stride Length

Stride length, walking forward at a usual speed ON medications, was close at all sites, with mean and standard deviation of approximately 109 centimeters. Stride length

was lower at the VA Group 1, specifically 94.12 ± 23.54 centimeters. Our findings agree with the stride length of 108.45 ± 23.86 centimeters walking over ground ON medications, in the study by Bryant and colleagues, that examined the effect of levodopa on different gait parameters (Bryant et al. 2011). Our stride length, walking forward ON medication was lower than the 130 ± 1 centimeters reported by Hackney and associates. However, it is important to point out that 80% of their subjects had mild disease severity (Hackney et al. 2009).

Stride length, walking over ground OFF medications, ranged from a low (mean and standard deviation) of 81.69 ± 29.16 centimeters at the VA Group 1 to a high of 100.29 ± 34.50 centimeters in Galveston, with the VA Group 2 and the combined group coming in between at 95.55 ± 22.75 centimeters and 98.88 ± 27.44 centimeters respectively. Comparative stride length (mean and standard deviation) in the study by Bryant and colleagues was 91.11 ± 26.09 centimeters, which was lower than all of our groups with the exception of the VA Group 1. Since inclusion criteria in the Bryant study required use of levodopa, perhaps their subjects had more motor fluctuations and were truly more incapacitated OFF medications. It should be noted that stride length was higher ON medications than OFF medications in this study, and in that of Bryant (Bryant et al. 2011).

Stride length, walking on the GAITRite ON medications ranged from a low (mean and standard deviation) of 96.70 ± 17.66 centimeters at the VA Group 1, to a high of 113.57 ± 26.57 centimeters at the VA Group 2, with Galveston and the combined group having stride lengths of 109.05 ± 21.51 centimeters and 112.20 ± 24.02 centimeters respectively. Walking forward on the GAITRite ON medications, our value for stride length was close to the 107.34 ± 23.31 centimeters reported by Bryant and

colleagues, in a study that compared walking on the GAITRite with walking over ground (Bryant et al. 2012).

Stride length OFF medications on the GAITRite, was lower than stride length ON medications, and ranged from (mean and standard deviation) of 78.74 ± 24.64 centimeters at the VA Group 1, to 99.64 ± 25.13 centimeters at the VA Group 2, with Galveston and the combined group in between at 93.83 ± 29.01 centimeters and 97.89 ± 26.35 centimeters respectively. Our values for stride length, OFF medications on the GAITRite, are similar to those of Bryant and colleagues in the study above, mean and standard deviation of 96.53 ± 25.96 centimeters (Bryant et al. 2012).

Walking Fast Forward – Velocity

There were several studies that examined velocity walking fast over ground ON PD medications. Reviewing our results, the mean and standard deviation for velocity ranged from a low of 116.28 ± 28.88 centimeters/second at the VA Group 1, to a high of 135.52 ± 36.27 centimeters/second at the VA Group 2, with Galveston and the combined Galveston VA Group 2 in between at 128.84 ± 28.09 centimeters/second and 131.46 ± 36.27 centimeters/second respectively. These values are consistent with those of Brusse and colleagues, who found that mean and standard deviation for fast velocity ON medications was 124 ± 33 centimeters/second, and that the confidence interval around the mean was 110-138 centimeters/second (Brusse et al. 2005). Similarly, in a study looking at the effect of walking speed and medication state on various gait parameters, Bryant and colleagues found that velocity ON medications (mean and standard deviation) was 135.76 ± 27.59 centimeters/second, which was in agreement with our highest velocity at the VA Group 2 (Bryant et al. 2011a). A study examining the performance of persons with PD on several balance and gait measures reported that velocity walking fast (mean

and standard deviation) was 147 ± 51 centimeters/second, and that the confidence interval around the mean was 130 -164 centimeters/second (Steffen et al. 2008). Mean velocity at the VA Group 2 and the combined Galveston VA Group 2 fell within their confidence interval. Finally, in a study on gait and lower extremity function in PD, Song and associates reported that mean velocity walking fast ON medications was 192 centimeters/second (Song et al. 2009). The discrepancy between the Song study and ours is most likely due to lower disease duration, disease severity, and less comorbidity in the Song participants, who were not yet taking any PD medications (Song et al. 2009).

Velocity, walking fast over ground OFF medications, was slower than walking ON medications at all sites. Velocity ranged from a low (mean and standard deviation) of 94.90 ± 30.90 centimeters/second at the VA Group 1, to a high of 124.08 ± 34.96 centimeters/second at the VA Group 2, with Galveston and the combined Galveston VA group falling in between at 116.39 ± 41.72 centimeters/second and 119.88 ± 38.31 centimeters/second respectively. There was just one study that examined fast walking OFF medications, and velocity (mean and standard deviation) was 123.91 ± 35.62 centimeters/second. This matched the velocity of our VA Group 2 but was higher than our remaining groups. The participants in that study had lower disease severity as measured by mean H&Y scale staging, 2.58 in their study participants compared to 3 in our participants (Bryant et al. 2011).

Velocity, walking fast on the GAITRite ON medications, was higher than walking over ground at all sites. Velocity (mean and standard deviation) ranged from a low of 136.75 ± 24.87 centimeters/second at the VA Group 1 to a high of 149.44 ± 33.23 centimeters/second at the VA Group 2, with Galveston and the combined Galveston VA group falling in between at 144.26 ± 30.97 centimeters/second and 146.60 ± 33.23 centimeters/second respectively. There were no other studies that could be found in the

literature where walking fast on the GAITRite ON medications was examined in patients with PD, so no comparisons could be made.

Velocity, walking fast on the GAITRite OFF medications, ranged from a low (mean and standard deviation) of 119.21 ± 40.53 centimeters/second at the VA Group 1, to a high of 143.19 ± 38.33 centimeters/second at the VA Group 2, with Galveston and the combined Galveston VA group in between at 127.80 ± 34.87 centimeters/second and 135.94 ± 37.19 centimeters/second respectively. There were no other studies that tested patients with PD under similar walking conditions to use for comparison.

Walking Backward – Velocity

Velocity walking backward was always slower than velocity walking forward, in both medication states, both on the GAITRite and over ground. This can be explained by several factors. First, fear of falling is greater walking backward, since the person cannot see where he/she is going. Trunk and neck rigidity prevent looking backward over the shoulder to see the walking path (Franzen et al. 2009). This fear is intensified when walking on the GAITRite, with the additional requirement of keeping the path in the center of the walkway. Patients are particularly anxious about tripping crossing over the end of the carpet, especially when they cannot see where it ends. It has been shown that fear of falling, age, disease severity, gender, and depression explain 37% of variability in walking performing a single task in persons with PD (Rochester et al. 2008). To compensate for the blinded pathway the subject must utilize increased attention, and prediction, both components of executive function. It has been shown that as attentional and executive demands increase, gait velocity decreases (Rochester et al. 2008; Yogev-Seligmann et al. 2008). In fact in healthy elderly individuals gait speed, controlling for gait dysfunction, is predicted by attention, speed of executive function, memory and verbal IQ (Holtzer et al. 2006). In Parkinson's disease, increased attention is already

required to compensate for the lack of automaticity of walking, that results from impaired basal ganglia function and shortage of dopamine (Morris, 2006). There are limits to attentional capacity, and it may clearly be met walking backward, especially in participants with moderate disease severity (Yogev et al. 2007).

Velocity, walking backward over ground ON medications, ranged from a low (mean and standard deviation) of 44.14 ± 14.93 centimeters/second at the VA Group 1, to a high of 78.74 ± 34.16 centimeters/second at the VA Group 2, with Galveston and the combined Galveston VA group in between at 67.08 ± 27.10 centimeters/second and 74.24 ± 31.88 centimeters/second respectively. Our results coincide with those of Hackney and colleagues, who found that gait velocity walking backward ON medications (mean and standard deviation) was 70 ± 20 centimeters/second, even though their subjects had less disease severity (Hackney et al. 2009). There was a discrepancy between our results and those of Bryant and colleagues, who looked at 21 patients with PD walking forward and backward. They found that the mean and standard deviation for velocity, walking backward over ground ON PD medications, was 58.71 ± 21.75 centimeters/second (Bryant et al. 2011b). Ninety percent of their subjects were reported to have freezing of gait, and 11 of the subjects reportedly had dyskinesias or extraneous movements following ingestion of their medications. It is possible that the dyskinesias interfered with the subjects' backward progression, and therefore reduced velocity. Alternatively, there was an overlap of some of the subjects in the current study and that of Bryant and associates, and perhaps this overlap included many of the subjects from the VA Group 1, explaining the low backward velocity (Bryant et al. 2011b).

Velocity, walking backward over ground OFF medications, ranged from a low (mean and standard deviation) of 36.62 ± 14.76 centimeters/second at the VA Group 1, to a high of 67.06 ± 36.09 centimeters/second at the VA Group 2, with Galveston and the

combined Galveston and VA group at 54.79 ± 28.91 centimeters/second and 62.11 ± 28.18 centimeters/second respectively. There were no other studies in the literature that measured walking backward OFF PD medications, so comparisons could not be carried out.

Walking backward on the GAITRite ON medications, velocity ranged from a low (mean and standard deviation) of 49.62 ± 22.98 centimeters/second at the VA Group 1, to a high of 69.63 ± 29.61 centimeters/second at the VA Group 2, with Galveston and the Galveston VA combined groups walking at velocities of 61.78 ± 19.78 centimeters/second and 66.57 ± 26.31 centimeters/second respectively. There were no comparative studies in the literature about persons with PD walking backward on the GAITRite ON PD medications. With the exception of the VA Group 1, ON medications walking backward over ground, was faster than walking backward on the GAITRite. This contradicts walking forward where speeds on the GAITRite were faster than those over ground. This will be discussed further under specific aim 3 that compares walking on the GAITRite and over ground.

Walking backward on the GAITRite OFF medications, velocity ranged from a low (mean and standard deviation) of 38.03 ± 22.78 centimeters/second at the VA Group 1, to a high of 66.70 ± 32.47 centimeters/second at the VA Group 2, with Galveston and the combined Galveston VA group at 50.23 ± 27.12 centimeters/second and 60.28 ± 31.31 centimeters/second respectively. It should be noted that the values for walking backward on the GAITRite and over ground were very similar, and this too will be expanded on under specific aim 3.

Walking Backward – Cadence

Cadence, walking backward ON medications over ground, ranged (mean and standard deviation) from a low of 117.41 ± 29.58 steps/minute at the VA Group 1, to a

high of 130.91 ± 35.67 steps/minute at the VA Group 2, with Galveston and the combined Galveston VA group in between at 124.56 ± 23.31 steps/minute and 128.46 ± 31.40 steps/minute respectively. Cadence in Galveston and at the VA Group 1 coincided with that of Bryant and colleagues, who compared walking forward and backward. Their cadence, walking backward over ground ON medications, was 121.56 ± 20.82 steps/minute (mean and standard deviation) (Bryant et al. 2011b). Cadence for our participants at the VA group 2 and in the combined Galveston VA2 group was higher than that of Bryant and colleagues' subjects. To explain this difference it may be necessary to look beyond cadence alone. Gait velocity is equal to the product of stride length and cadence. In Galveston and at the VA Group 1, the numeric value for gait velocity and stride length were approximately equal as was the case for the subjects in the study by Bryant and colleagues. However, at the VA Group 2 and in the combined Galveston and VA group, since the numeric value for gait velocity was significantly higher than stride length, cadence would have needed to increase to account for the higher velocity.

Cadence, walking backward over ground OFF medications, ranged from a low (mean and standard deviation) of 112.14 ± 21.75 steps/minute at the VA Group 1, to a high of 139.41 ± 33.03 steps/minute at the VA Group 2, with Galveston and the combined Galveston VA group in between at 117.95 steps/minute and 130.75 ± 32.63 steps/minute respectively. Again, cadence walking backward OFF medications in Galveston and the VA Group 1 was similar to that of Bryant and colleagues, which was 116.87 ± 30.21 steps/minute (Bryant et al. 2011b). Consistent with cadence walking backward ON medications, cadence values at the VA Group 2 and in the combined Galveston VA Group 2 were higher and similarly explained.

Cadence, walking backward on the GAITRite ON medications, was similar in Galveston and at the VA Group 1, with a mean of 109.89 steps/minute and 109.99 steps/minute respectively. Moreover, cadence at the VA Group 2 and in the combined Galveston VA group was close at 114.74 ± 28.06 steps/minute and 112.85 ± 26.36 steps/minute. With the exception of Galveston, where cadence (mean and standard deviation) was 102.93 ± 38.92 steps/minute, the range for cadence walking backward on the GAITRite OFF medications was tight, from 109.77 ± 34.60 to 114.14 ± 31.42 steps/minute. There were no studies in the literature, where patients with PD walked backward on the GAITRite both ON & OFF PD medications.

Walking Backward – Stride Length

Walking backward over ground ON medications, the range for stride length (mean and standard deviation) was tight, between 66.08 ± 28.43 centimeters and 68.32 ± 30.82 centimeters at all sites. The only exception to this tight interval was the VA Group 1, where stride length was much lower, at 48.21 ± 19.55 centimeters. The reduced stride length at the VA Group 1, was most likely due to the increased disease duration and severity of those participants. Our values for stride length walking backward were higher than those of Bryant and colleagues, that were (mean and standard deviation) 60.12 ± 24.01 centimeters (Bryant et al. 2011b), but were slightly lower than those of Hackney and associates, that were (mean and standard deviation) 70 ± 1 centimeters (Hackney et al. 2009). There was some overlap between subjects in the Bryant study and our study, with all her participants coming from the VA, where subjects in the VA Group 1 probably lowered stride length walking backward over ground ON medications (Bryant et al. 2011b). Almost 77% of the participants in the Hackney study had mild disease severity, thus explaining their higher stride length (Hackney et al. 2009).

The range for stride length, walking backward over ground OFF medications, was wider than the range for stride length walking backward ON medications. Stride length (mean and standard deviation) ranged from 52.95 ± 22.89 centimeters to 57.90 ± 22.93 centimeters at all sites, again with the exception of the VA Group 1 where it was considerably lower at 30.85 ± 16.14 centimeters. Bryant and colleagues reported that stride length (mean and standard deviation) walking backward over ground OFF medications was 48.21 ± 17.87 centimeters, lower than ours. Again the difference in stride length walking backward was probably due to an overlap in participants in the two studies with the inclusion of subjects from the VA Group 1 by Bryant and colleagues (Bryant et al. 2011b).

Walking backward on the GAITRite ON medications, stride length values were similar at all sites with the exception of the VA Group 1, and ranged (mean and standard deviation) from 69.36 ± 23.13 centimeters to 73.96 ± 24.36 centimeters. Stride length, walking backward on the GAITRite ON medications, was much lower at the VA Group 1, with a mean and standard deviation of 55.95 ± 23.97 centimeters. The explanation for the lower stride length at the VA Group 1 has been discussed above. There were no other studies with patients with PD walking backward on the GAITRite ON medications.

Finally, walking backward on the GAITRite OFF medications, stride length varied more with a low (mean and standard deviation) of 42.41 ± 24.21 centimeters at the VA Group 1, to a high of 70.27 ± 28.84 centimeters at the VA Group 2, with Galveston and the combined Galveston and VA group in between at 59.21 ± 24.88 centimeters and 65.96 ± 27.68 centimeters respectively. There were no articles in the literature that examined walking backward on the GAITRite OFF medications.

Comparing Forward and Backward Walking

Gait velocity is the product of stride length multiplied by cadence. Forward velocity was approximately 25 centimeters/second higher than backward velocity, under both walking conditions, and in both medications states. Similarly stride length was approximately 40 centimeters/second longer walking forward than backward, again under both walking conditions, and in both medications states. Cadence was more complicated – there was minimal difference walking forward and backward on the GAITRite in both medications states; over ground cadence was 20 steps/minute greater walking backward than forward in both medication states. Thus walking over ground, it appears that the higher velocity forward resulted from longer stride length and fewer steps per minute. Conversely walking on the GAITRite, it appears that the higher velocity walking forward was simply the result of increased stride length with cadence remaining the same. Our findings for cadence walking over ground coincide with those of Bryant and Hackney; however neither of the two studies looked at walking forward and backward on the GAITRite (Bryant et al. 2011b; Hackney et al. 2009). Backward velocity is further constrained by the stooped posture and posterior pelvic tilt that limit extension of the thigh (Franzen et al. 2009).

Hypothesis 3: Correlations of Gait Parameters with the UPDRS Total Score

Walking Forward at a Usual Speed

There were no significant correlations between any of the gait variables (velocity, cadence, stride length) and the total score of the UPDRS, both walking on the GAITRite and over ground, and both ON & OFF PD medications. This is in agreement with a study by Brusse and colleagues, who compared velocity, walking forward at a comfortable speed over ground ON medications, with the UPDRS total and section scores (Brusse et

al. 2005). Their subjects were slightly older (76 versus 69 years old), slightly less involved as measured by mean H&Y stage (2 versus 2.5), and equivalent in comorbid neurological and cardiac conditions. There was a discrepancy between our findings and those of Song and colleagues, who found a significant Pearson product correlation between comfortable walking speed over ground ON PD medications and the UPDRS total score ($r = 0.522$, $p = 0.003$), the UPDRS ADL section ($r = 0.386$, $p = 0.04$) and the UPDRS motor section ($r = 0.453$, $p = 0.003$) (Song et al. 2009). The subjects in the Song study were much younger (62 versus 69 years old), were less involved as measured by mean H&Y stage (1.9 versus 2.5), and were healthy without significant comorbid disease. Even though the correlation between usual gait speed and the UPDRS total score was fair, the variance was low, suggesting that constructs besides gait contribute to predicting UPDRS total score (Song et al. 2009) The short length, and absence of acceleration and deceleration areas on our walkway, may have prevented our participants from optimizing velocity. Alternatively, our subjects may have experienced a ceiling effect in velocity, because of their greater disease burden and comorbidities.

Walking Forward at a Fast Speed

There were no significant correlations between any of the gait parameters (velocity, cadence, stride length) and the UPDRS total score when walking forward at a fast speed, both on the GAITRite or over ground, and ON & OFF PD medications. This coincides with the finding in the Brusse study where gait velocity walking at a fast speed did not correlate with the UPDRS total score or any of the section scores (Brusse et al. 2005). There was a discrepancy between our findings and those of Song and colleagues, who reported a significant correlation between velocity walking fast forward and the UPDRS total score ($r = 0.544$, $p = 0.002$) and the UPDRS motor section score ($r = 0.563$, $p = 0.001$) (Song et al. 2009). Whereas the subjects in the study by Song and colleagues

were able to achieve fast gait velocities of 192 centimeters/second on a 15 meter walkway, the highest gait velocity for our fastest group walking fast on a 5 meter walkway was 135.52 ± 36.04 centimeters/second. Again, the younger age, shorter disease duration, lower disease severity, and absence of comorbidities in the participants in the study by Song and colleagues, may have accounted for the lower fast gait velocity in our participants (Song et al. 2009). Perhaps our 5 meter walkway, without acceleration and deceleration areas, was of insufficient length to allow our subjects to maximize gait velocity enough to correlate with the UPDRS. More likely, the burden of age and disease severity prevented our participants from achieving fast gait velocities similar to those of the participants in the study by Song and colleagues (Song et al. 2009).

Walking Backward

There were no significant relationships between any gait parameter (velocity, cadence, stride length) and the UPDRS total score walking backward, both on the GAITRite and over ground, in both medication states. There were no studies in the literature which examined the relationship between walking backward and the UPDRS total score.

Hypothesis 3: Correlations of the Gait Variables with each Other

Correlations of Gait Measures ON & OFF PD Medications

Gait velocity OFF medications was significantly associated with gait velocity ON medications, both walking forward and backward, and walking at usual and fast speeds. Studies have shown that gait velocity increases significantly when individuals with PD transition from OFF to ON PD medications (Lubick et al. 2006; Moore et al. 2008; Bryant et al. 2011a; Bryant et al. 2011b). It appears that patients with PD have the ability to increase walking speed enough for significant differences ON & OFF PD medications

(Moore et al. 2008; Lord et al. 2011). Nevertheless, disease severity and non-motor complications of PD, ultimately limit the increase in gait velocity that is possible (Song et al. 2009). This may explain why velocity scores ON & OFF PD medications were related.

Stride length OFF medications was also significantly related to stride length ON medications, walking forward and backward at comfortable speeds. Stride length has been shown to be dopamine sensitive, resulting in significant differences between walking ON & OFF PD medications (Blin et al. 1991; Lubick et al. 2006; Lord et al. 2011; Bryant et al. 2011a). The inability to generate adequate stride length is the fundamental problem underlying the slow gait in PD (Morris et al. 1994). Stride length decreases as disease severity increases (Moore et al. 2008). Disease severity limitations on stride length might explain the correlation seen between ON & OFF PD medications for stride length, both forward and backward.

Cadence has been shown to be resistant to dopamine, but is often the way patients with PD compensate for the reduced stride length (Morris et al. 1994; Morris et al. 1996b; Morris et al. 2009). This could explain why, for the most part, there were no significant relationships between cadence walking forward on the GAITRite and over ground, at a usual or fast speed, and in both medication states. There was a single significant relationship between cadence walking backward on the GAITRite ON & OFF PD medications.

Correlations between Gait Velocity and Stride Length

It is not surprising that there were several correlations between gait velocity and stride length, when in the same medication state. These associations were found over ground predominantly OFF medication, walking forward and backward. On the GAITRite, relationships between gait velocity and stride length were found walking

forward at a usual and fast speed, both ON & OFF PD medications. A study by Thomas and colleagues compared normal and fast walking times over ground (items 26 and 27 on the GABS), with each of the parameters measured on the GAITRite (Thomas et al. 2004). Both normal and fast gait speed, were associated with mean ambulation time and mean velocity on the GAITRite ($p < 0.01$). Additionally, fast gait velocity was related to mean step length and stride length on the left, supporting our findings (Thomas et al. 2004).

Correlations between GAITRite and Over Ground Walking in the Same Medication State

The majority of correlations between walking on the GAITRite and over ground were found when participants walked backward. Velocity, walking backward on the GAITRite, correlated with velocity walking backward over ground, both ON & OFF PD medications. Similarly, stride length walking backward on the GAITRite, correlated with stride length walking backward over ground, both ON & OFF PD medications. Participants were most anxious about walking backward on the GAITRite, since it required both keeping themselves centered on the walkway, and making the toe heel contact in order for the sensors to record. They were also fearful of tripping on the edge of the walkway especially since they could not look over their shoulder to see where they were going. Conversely, walking over ground they did not need to worry about centering their path, contacting the floor firmly with the toes and then the heel, or tripping over the edge of the walkway. Perhaps, the added demands of walking on the GAITRite, slowed down the speed and shortened the stride length of the participants, to the point where it matched the same parameters measured walking backward over ground.

Hypothesis 4: Correlations of Gait Parameters with the UPDRS Motor Section

There were no significant correlations between any of the gait variables (velocity, cadence and stride length) and the motor section score of the UPDRS, regardless of

walking direction or speed. Brusse and colleagues also found no correlations between any of the gait parameters (gait velocity, cadence and stride length) and the motor section of the UPDRS, when 25 persons with PD, (mean H&Y stage 2, mean age 76 ± 7 years), walked forward at a comfortable speed along a 10 meter walkway (Brusse et al. 2005). There was a discrepancy between our findings and those of Song and colleagues. They reported an association between comfortable walking speed and the motor section of the UPDRS ($r = 0.453$, $p=0.012$), and fast walking speed and the motor section of the UDPRS ($r =0.563$, $p =0.001$) when persons with PD, (mean age 62.9 ± 11.7 years, and mean H&Y stage 1.9), walked along a 15 meter walkway (Song et al. 2009). In the study by Song and associates, in addition to walking at usual and fast speeds, lower extremity function was evaluated climbing 6 steps, and transferring sit to stand 10 times repetitively. These two additional measures also correlated significantly with the UPDRS total and motor section scores. Since gait at a usual and fast speed, stair climbing and repetitive transfers from sit to stand all correlated significantly with the UPDRS total and motor scores, the authors concluded that the two UPDRS scores might be good predictors of lower extremity function in PD, and possibly shared some overlapping constructs (Song et al. 2009). Returning to our failure to find significant correlations of any gait parameters with the UPDRS total and motor scores, perhaps the longer walking distance, acceleration and deceleration areas at each end, and the analysis of data from the center of the walkway in the study by Song and colleagues, allowed gait parameters to correlate with the UPDRS total and motor scores, where our parameters did not (Song et al. 2009).

SPECIFIC AIM 2

Correlations of Performance Based and Self-Perceived Balance Tests

There was a significant relationship between the Activities Specific Balance Confidence Scale (ABC) and the Gait and Balance Scale (GABS), turning 360 degrees to the right, and the PIGD index, all OFF PD medications. None of the performance balance measures ON medications were significantly correlated with the ABC. It is interesting that turning was one of the performance balance measures that were directly related to the ABC self-perceived balance confidence scale. The PIGD index has been used as a surrogate for turning in some research studies in individuals with PD (Salarian et al. 2009). Difficulty turning is reported in 52-60% of patients with PD (Crenna et al. 2007). Additionally, difficulty turning is associated with freezing of gait and increased falls risk in PD (Schafsma et al. 2003; Bloem et al. 2004). Turning challenges postural reactions due to destabilization of the head and neck on the trunk, and the trunk segments on one another. Patients with mild PD who have normal gait kinematics and stride parameters, normal range of motion in the torso and lower extremities, absence of both freezing of gait and rigidity, execute turns differently than healthy age-matched controls. They approach the turn more slowly, take longer to turn, and require more steps to execute the turn (Salarian et al. 2009). They lose the normal eye-head-trunk spatiotemporal sequencing that is required to orient gaze to the intended direction, and to stabilize axial segments of the trunk upon each other. In PD, the segmental rotation that usually occurs between the cervical and trunk segments is lost. Both regions move together and later into the turn, resulting in decreased overall rotation in both areas by mid-turn (Crenna et al. 2007). It is possible that even very early in the progression of PD, patients adopt a compensatory strategy to reduce the destabilizing forces of turning, that includes moving the head and torso simultaneously, and taking more steps in the turn (Crenna et al. 2007).

The freezing up of degrees of freedom in the trunk is not limited to turning, but has also been described during walking, in patients with PD in H&Y stages 2-3, in the absence of trunk rigidity (Mesure et al. 1999). The existence of a group of patients with mild PD with normal walking but abnormal turning, suggests that there might be separate neural mechanisms and pathways controlling each task. It was suggested that there might be greater supraspinal circuitry involved in turning (Crenna et al. 2007). In animal studies there is strong support for a pathway governing sequencing of eye, head and neck, and trunk movements for turning. It is thought to extend from the frontal and supplementary eye fields, project through the caudate nucleus and substantia nigra, descend through the superior colliculi and midbrain reticular area (with the pedunculopontine nucleus), and ultimately descend to the spinal cord motor neurons through the reticulospinal and tectospinal tracts (Crenna et al. 2007). Patients with PD are known to have deficits in the trigemino-cervical-spinal pathways, (consistent with the brainstem and spinal portions of the pathway above), shown to be resistant to dopamine, and associated with neck rigidity and postural instability (Perotta et al. 2005). Damage to these pathways may account in part, for the coupled neck and shoulder rotation, seen during turns and walking in PD (Crenna et al. 2007). It is known that the frontal lobe supplemental eye field area is adjacent to the anterior part of the supplemental motor area and its projections to the basal ganglia, caudate nucleus, and substantia nigra. It has been suggested that this might account not only for the loss of the exploratory eye movement and gaze stabilization in turning, but also the spatiotemporal sequencing of eye head and neck movement while turning (Crenna et al. 2007). Patients with PD are known to have deficits with saccadic eye movement, and the pathway controlling this is largely the same as the supplemental eye field caudate and substantia nigra circuitry for turning (Chan et al. 2005; Crenna et al. 2007). The profile of patients with PD with normal walking but deficits in turning, raises

the possibility that the mechanisms that coordinate turning might be more susceptible to deterioration than the mechanisms that coordinate walking (Crenna et al. 2007).

The GABS correlated negatively with the ABC 16 item scale ($r = -0.732$). The GABS is a disease specific evaluation instrument developed to measure both gait and balance, while the ABC scale is a general measure of balance self-efficacy in the elderly population (Powell et al. 1995; Thomas et al. 2004). Two of the disease specific items of the GABS are included in the non-performance historical section, specifically item 6 freezing of gait, and item 7 modifying factors for freezing of gait. There is a single performance item (item 22) on provoking freezing of gait when walking. The remaining items are not disease specific and can be used to evaluate gait and balance in the elderly population (Thomas et al. 2004). Perhaps there are enough non-disease specific items on the GABS that enhanced its correlation with the ABC scale. The items on both scales can be divided into balance and walking items. For the GABS the balance items include - rising from a chair, posture, postural stability, balance feet together eyes open and the Romberg its equivalent, eyes closed, single limb and tandem stance, functional reach, and foam posturography (Thomas et al. 2004). The ABC balance items relate more to daily living tasks and include - reaching at eye level, reaching on tiptoes, reaching while standing on a chair, sweeping the floor and transferring into and out of the car (Myers et al. 1998). The gait items on the GABS include - walking 5 meters, turning 180 degrees after walking, turning 360 degrees in both directions, walking on toes on heels and tandem, and the gait items from the performance oriented movement assessment (POMA) gait section (Tinetti 1996; Thomas et al. 2004). The walking items on the ABC include - walking around the house, outside to a nearby car, across a parking lot, up and down a ramp, in a crowded mall without and with being bumped, and on icy sidewalks. Riding an escalator holding and not holding the rail have elements of gait and balance – the gait

stepping on and off the escalator, and the balance riding the escalator (Myers et al. 1998). The range of difficulty of items seems to be broader on the ABC scale than on the GABS. In this study the GABS was measured both ON & OFF PD medications, while the ABC was measured a single time after ingestion of the PD medications and waiting for them to take effect. Only the GABS OFF medications correlated with the ABC scale. In a sample of 35 subjects with PD (20 female, ages 50-75 years, H&Y stages 1-3), who performed the GABS ON & OFF PD medications, there was a significant 3 point difference between scores ON & OFF PD medications, with scores higher OFF medications ($p=0.024$) (Thomas et al. 2004). There is support in the literature that OFF medication testing may be more accurate than ON medication testing. A study was conducted to compare the predictive validity of the functional gait assessment (FGA), timed up and go (TUG) and pull test to identify persons with PD who fall, both ON & OFF PD medications. First, the FGA and TUG were the only measures that were significantly different ON & OFF PD medications. The participants were categorized into faller and non-faller groups. While the FGA could distinguish between the falls categories ON & OFF PD medications, the TUG could only differentiate between fallers and non-fallers OFF medications. The fall history effect size was higher for all tests OFF medications. Finally a measure for accuracy of the test, the area under curve (AUC) for the receiver operated characteristic (ROC) curve, was significantly higher for the FGA compared to the pull test, but only OFF medications (Foreman et al. 2011). Another study compared the pull test and push and release tests ON & OFF PD medications, and found that the AUC values were greater OFF medications than ON medications (Valkovic et al. 2008).

The PIGD index (items 27-30 on the UPDRS) has been used as a proxy measure for turning, since there is no single item on the UPDRS that captures that task (Salarian et al. 2009). The moderate relationship of the PIGD index to the ABC scale, found in our

study, is supported by the current literature. A study whose purpose was to validate shorter versions of the ABC scale, evaluated 89 persons with PD, (mean age 66.5 ± 9.8 , mean H&Y stage 2.3 ± 0.5 and mean disease duration 8.2 ± 5.2 years), found that there were significant correlations between all versions of the ABC scale, long or short, and the PIGD index (items 27-30 of the UPDRS) (Lohnes et al. 2010). The PIGD index measures many of the situations where falls are reported to occur most frequently in individuals with PD namely, walking (45%), standing (32%), and transferring from sitting to standing (15-24%) (Bloem et al. 2001; Ashburn et al. 2008). If the PIGD index measures fall provoking activities and correlates with the ABC scale, then what exactly is the ABC scale measuring - balance confidence or fear of falling (FoF)? Are balance confidence and fear of falling the same? Second, does fear of falling cause falls, or does a previous fall cause fear of falling (Mak et al. 2009a)? The precursor to the ABC scale, the 10 item Falls Efficacy Scale (FES), was developed to measure fear of falling in the elderly while performing fairly global daily activities, like simple shopping or reaching up into cabinets (Tinetti et al. 1990). The 16 item ABC scale was developed in an attempt to clarify the ambiguity of items on the FES, and to broaden its scope (Powell LE et al. 1995). While the question posed on the original FES instrument was how likely are you to fall while performing each of the 10 activities that follow, the question raised on the ABC scale is how confident are you that you would be able to perform each of the 16 daily tasks, a shift in paradigm from fear of falling, to balance self-efficacy (Tinetti et al. 1990; Powell et al. 1995). Some researchers still assume that the ABC is a measure of fear of falling or speculate that balance confidence and fear of falling are the same or similar constructs (Landers et al. 2008; Mak et al. 2009a; Lohne et al. 2010). This has even led to the contention that balance confidence, as measured by the ABC, can predict falls risk (Mak et al. 2009a). Furthermore, the ABC scale has been utilized to discriminate fallers from

non-fallers, and single from recurrent fallers (Mak et al. 2009a; Mak et al. 2009b; Mak et al. 2010). The reader should be cautious not to jump to the conclusion that the only reason a person might perceive difficulty performing an activity is fear of falling.

One of the observations during testing was that patients had varying insight into the limitations of their disease, and its implication for functional mobility and activities of daily living. Those with intact executive functions, specifically insight and problem-solving, were likely aware of their limitations and were possibly modifying their movement strategies to limit postural instability and falls. On the other hand, there were participants, especially those with executive dysfunction or denial, who were not aware of the limitations their disease imposed. It is only with awareness of functional limitations that individuals might be ready to learn alternative movement strategies to optimize function. It has been suggested that therapists need to educate patients so that they are aware of their limitations, and might therefore be ready to modify their movements to maximize ability and limit disability (Mak et al. 2009a; Mak et al. 2009b). When awareness of functional mobility and ADL status and actual performance do not coincide, the patient might be at increased risk for postural instability and falls. There were participants whose confidence in mobility was lower than their actual performance. These patients need education to help them see their potential, and their physical therapy training needs to help them explore this untapped potential safely (Mak et al. 2009a). Therefore, despite the significant correlations between performance and self-perceived measures of balance, it is probably important to evaluate both.

Correlations of Balance Measures ON & OFF PD Medications

All six balance measures OFF medications were highly correlated with the same measures ON medications, with correlations ranging from 0.725 – 0.862. The highest

correlation was for the GABS ON & OFF PD medications, and the lowest correlation was for turning to the right ON & OFF PD medications. The higher correlations were for measures not known to be influenced by dopamine pathways, specifically 360 degree turns and the PIGD index, both measures of postural stability and gait (Adkin et al. 2003; Franzen et al. 2009). The lowest correlation was for the UPDRS total score, where many items are known to improve with dopamine, specifically bradykinesia, tremor, manual dexterity and agility, and possibly rigidity especially distally (Adkin et al. 2003). The correlation between turning 360 degrees in both directions, OFF and ON medications was excellent ($r = 0.860 - 0.939$). This makes sense because turning 360 degrees requires inter-limb coordination to accomplish the task (Stack et al. 2006; Huxham et al. 2008a; Huxham et al. 2008b; Stack et al. 2008; Salarian et al. 2009). Correlations were intermediate, but still strong, for the GABS, PIGD, and 5 step test OFF versus ON medications, with correlations ranging from 0.81 - 0.84. Since the balance measures we used were not dopamine sensitive, it makes sense that the ON & OFF PD medication test results would be highly related. Additionally, our balance measures, especially the 5 step test and turning 360 degrees were sufficiently challenging that participants reached their maximum capacity OFF medications, and had little room to improve ON medications. Alternatively, individuals may not have reached maximum capacity OFF medications, but they soon reached their maximum and slowed down ON medications, to maintain postural stability (Crenna et al. 2007; Cole et al. 2010).

Correlations between PIGD index and GABS ON & OFF PD Medications

There was a significant relationship between the GABS OFF medications and the PIGD OFF medications. Similarly, the GABS ON medications was significantly related to the PIGD ON medications. This would lead one to believe that both the GABS and the

PIGD might be sensitive to the effects of dopamine. Franzen showed that the BBS and FRT, both part of the GABS, were sensitive to dopamine (Franzen et al. 2009). The UPDRS, which contributes items to both the GABS and PIGD index, was also influenced by dopamine, with scores significantly lower ON medications (Franzen et al. 2009). Moreover the TUG, also a part of the GABS but not included in the score, was not sensitive to dopamine (Franzen et al. 2009). Franzen suggested that axial tone is related to balance, turning, and gait. ON medication there were significant correlations between neck tone with both the BBS and FRT. The TUG was associated with neck tone OFF medications. There was a relationship between axial tone and performance on the PIGD ON & OFF PD medications, such that the PIGD index related to neck tone exclusively OFF medication, and related to trunk tone both ON & OFF PD medications (Franzen et al. 2011). It is known that postural stability and falls do not improve with dopamine (Morris et al. 2001; Adkin et al. 2003; Bryant et al. 2011). Temporal but not spatial parameters of gait are responsive to dopamine (Bryant et al. 2011; Foreman et al. 2011). Perhaps enough items on the GABS and PIGD respond differently ON & OFF PD dopamine, for the relationship between the GABS and the PIGD index to exist exclusively in the same medication state.

Another possible explanation for the relationship between the GABS and the PIGD index is the overlap of items between the two tests. Nine of the 17 performance items on the GABS are related to postural stability, while the remaining 8 items are related to gait. Sixty percent of the items on the UPDRS PIGD evaluate balance, while the remaining 40% of the items examine issues related to gait. Fifty percent of the items on the motor section PIGD are related to balance, and the remaining 50% pertain to gait. Posture, postural stability/retropulsion, and gait are three performance items on the GABS and PIGD index that are identical and scored in the same way. In the current

study, participants performed the GABS and the UPDRS separately, and in a set order, both ON & OFF PD medications. There was no automatic transfer of scores from one test to the other. The items on falls and freezing were common to both tests, and were collected by self-report. Participants were asked these items individually for the GABS and the UPDRS. Additionally, the speed for usual and fast walking, as well as for performing the TUG, are not included in the GABS score. Finally, both the GABS and the PIGD index are specific to PD, unlike some of the other measures (Thomas et al. 2004). Only a few of the performance items on the GABS are difficult enough to show dysfunction in mild PD, specifically, standing tandem, standing on one leg, and standing on foam with eyes closed. Similar to the PIGD index, most of the remaining items on the GABS would not detect impairments, functional mobility, and activity deficits in early PD (Salarian et al. 2009).

The PIGD index, derived from items 27-30 on the UPDRS, has been used in a number of studies. Adkin and colleagues set out to determine whether qualitative measures of balance, specifically fear of falling and the PIGD index, could predict quantitative measures of balance, specifically sway area of the center of body mass (COBM) on a force platform, when participants performed 8 different balance tasks (Adkin et al. 2003). The PIGD was significantly related to the sway area of the COBM, such that as PIGD scores increased sway area of the COBM also increased. Using regression analysis, the PIGD index explained a portion of the variation in sway area of the COBM for standing normally on a foam cushion ($R^2 = 0.28$), standing feet together with eyes closed ($R^2 = 0.24$) and standing feet together with eyes open ($R^2 = 0.28$). The PIGD index explained a significant portion of stance duration standing on one leg ($R^2 = 0.50$), however none of these predictions reached significance. The only one of these items that is not part of the GABS is standing on foam (Adkin et al. 2003). When Adkin

added the ABC scale scores to the regression model, together they explained a larger portion of the variability in sway area of the COBM, specifically for normal stance eyes open ($R^2 = 0.33$, $p < 0.07$), normal stance eyes closed ($R^2 = 0.56$, $p < 0.001$), standing feet together eyes open ($R^2 = 0.59$, $p < 0.001$), standing feet together eyes closed ($R^2 = 0.53$, $p < 0.005$), and standing feet together with a push/pull threat ($R^2 = 0.41$, $p < 0.05$). As the PIGD index increased, ABC scale scores decreased, and sway area of the COBM increased (Adkin et al. 2003). The overlap of these items with those on the GABS can readily be seen. The author suggested two reasons why the PIGD index alone could not predict COBM sway area. The first was that the PIGD index was measuring a different component of postural control than COBM sway area. The second suggested that the PIGD scale may be inadequate in accurately estimating postural stability due to its subjective scoring (Adkin et al. 2003). Since retropulsion is performed differently by most evaluators, the accuracy of this measure has been challenged (Bloem et al. 2001; Adkin et al. 2003). Just like the PIGD measures postural stability, the GABS was shown to be associated with several balance parameters measured by the Smart Balance Master (Neurocom, Klackamus OR) limits of stability test, for example excursion of movement, peak movement amplitude, and directional control, (Thomas et al. 2004). Salarian used the PIGD index as a surrogate measure for turning in a study that tried to mathematically model 180 degree turns done in the course of walking. Salarian compared 12 patients with PD, (H&Y stages 1-2.5, mean and standard deviation for the UPDRS motor section score of 20.3 ± 9.8), with 12 age matched control subjects. He found that while all of the control subjects had scores of 0 on the PIGD index, 7 persons with PD had scores of 0, 3 persons with PD had scores of 1, and 1 each of persons with PD had PIGD scores of 2 & 3. Individuals with PD took significantly longer to turn, had more double steps during the turn, and had increased duration of the step before the turn. One conclusion was that the

PIGD was not a sensitive measure in early PD, before individuals started taking dopaminergic medications. Another interesting finding was that over the 18 months that the subjects were followed, there was a further increase in the duration of the turn, and therefore, this variable might be a sensitive measure for disease progression in early PD (Salarian et al. 2009).

Correlations between the 5 Step Test and Turning 360 Degrees ON & OFF PD Medications:

The 5 step test OFF medications, was significantly correlated with turning 360 degrees to the (L) OFF medications ($r = 0.700$, 95% confidence interval 0.571 - 0.795) and turning to the right (R) ON medications ($r = 0.650$, 95% confidence interval 0.506 - 0.759). The 5 step test ON medications, did not correlate with any of the other tests. The fact that the correlation varied for turns to the right and left can most likely be explained by the asymmetry seen between the two sides of the body in the early stages of PD (Morris et al. 2001a). The 5 step test and timed turning 360 degrees are the two measures selected in our study to measure dynamic balance, so it is not surprising that they are significantly associated. Both are measures of dynamic balance, a construct where the COBM and BOS move, often at varying times, and through varying excursions (Horak et al. 1996; Shumway Cook et al. 1997). Dopaminergic medications are not known to improve the postural stability needed for dynamic balance (Horak et al. 2005). During turning 360 degrees and climbing up and down a step 5 times, the performer is moving in an environment that is not changing. Both tasks require feedback from the ongoing movement, and prediction, (based on past experience) to make adjustments for forthcoming movements (Horak et al. 1996; Shumway Cook et al. 1997). Both measures have periods when vision and proprioception are limited, forcing reliance on the vestibular system (Whitney et al. 2000). Additionally, both the 5 step test and turning 360

degrees, provide for changes in directions, again stimulating the vestibular system. During the 5 step test, the individual with PD is changing direction in an anterior-posterior direction. There is a possibility that the participant changes the technique of stepping up and down during the 5 repetitions, for example changing the leading leg up and/or down. It is probable that the person with PD places each foot in different places on the step from repetition to repetition. Similarly, as the person dismounts it is again likely that the foot placement on the ground will vary from trial to trial. Stepping backwards is done with limited visual input. Mounting and dismounting the step are both carried out in single leg stance. Similarly, when the individual with PD turns 360 degrees in either direction, the person is changing direction laterally, but repetitively. The participant is most likely taking different size steps, with different turning angles around the turn. Patients with PD may pivot on one leg during turning in the early stages of the disease, however when postural stability is compromised, both the number of steps to turn and their duration increase to replace pivoting (Horak et al. 2005; Shumway Cook 2007; Huxham et al. 2008a; Huxham et al. 2008b). Only the turn to the left ON medications was significantly associated with the 5 step test. A possible explanation for the reduced correlation with the 5 step ON medications is that our subjects showed more variability ON medications, possibly in part due to dyskinesias.

Correlations between Turning 360 Degrees to the Right and Left:

There was an excellent correlation between turning 360 degrees to the left (L) and right (R), both OFF medications ($r = 0.860$, 95% confidence interval 0.792 - 0.907), and ON medications ($r = 0.749$, 95% confidence interval 0.637 - 0.830), and to the (L) ON medications ($r = 0.762$, 95% confidence interval 0.684 - 0.839). The fact that turning 360 degrees to the (L) correlates so strongly with turning to the (R) makes sense given that

turning appears to be immune to the effects of dopamine. Additionally, the two sides of the body are closely linked through axial rotation of the trunk, and ongoing feedback from the placement of one foot influences the position of the foot that follows (Franzen et al. 2009). For example, if the person starts turning to the right, the right leg leads, pivoting early in the disease, and later barely clearing the floor; the left leg follows catching up to the lead leg, using ongoing feedback from the movement. The second leg cannot overtake the lead leg without seriously compromising balance. While Schenkman showed that axial rotation is reduced even in persons with mild PD, compared to age-matched control subjects, the reduction in axial rotation does not appear to have functional implications until the transition to moderate disease severity at H&Y stages 2.5 - 3 (Wang et al. 2005; Franzen et al. 2009). In PD, the pattern for the movement, in this case turning 360 degrees, usually remains intact, however the ability to execute or scale the amplitude of the movement falls short (Morris et al. 2001a). Taking small shuffling steps not only reduces the amount of axial rotation, but also the degree of prediction needed in a turn. Given the excellent association not only between left and right side 360 degree turns, but also the excellent association between 360 turns in both medication states, it may not be necessary to evaluate turning to both sides, and in both medication states.

SPECIFIC AIM 3

Specific aim 3 examined whether gait parameters measured on the GAITRite were equivalent to the same gait parameters measured with timed walking over ground. Accurate assessment of gait is important in the clinical setting, however the space, time personnel, and economic constraints prevent routine use of computerized gait analysis, three dimensional motion analysis, and electronic footfall recording. Practical constraints

prevent the use of paper imprint methods using ink or chalk, which can be messy, and require measurement done separate to testing. Clinicians generally do not evaluate temporal or spatial aspects of gait, possibly because they do not see velocity or stride length or cadence as important outcome measures, or because they do not know how to do the calculations to generate them. Studies have shown that measurements from computerized gait analysis systems, 3 dimensional motion analysis, and electronic footfall measurement are equivalent to those obtained on the GAITRite (Thomas et al. 2004; Chien et al. 2006; Mirek et al. 2007; Bryant et al. 2012). It has been shown that paper imprint methods of gait analysis also correlate with walking on the GAITRite (Beauchet et al. 2008). What is needed is a simple clinical measure that could be carried out quickly without the need for bulky equipment, and within the constraints of therapy evaluation and treatment time, that would provide clinicians with the information needed to design evidence-based gait training interventions. Thus, it would be appealing if timing gait with a stop-watch over a fixed distance, while simultaneously counting number of steps to walk this distance could, with some simple calculations, generate quantitative information on velocity, cadence, and stride length, which is an accurate estimate of the same parameters on the high technology computerized GAITRite. For persons with PD we chose to evaluate stride length, gait velocity, and cadence, first since these parameters are easy to compute from timed walks by counting steps, and second since it has been well documented that the predominant deficit in gait in PD is in stride length. In fact, patients with PD often use cadence to compensate for the deficient stride length (Morris et al. 1994; Morris et al. 1996; Schafsma et al. 2003, Cole et al. 2010). We compared measuring velocity, cadence, and stride length, in patients with mild to moderate PD, who walked first on the GAITRite and then over ground, both OFF medications when performance was likely to be worst, and ON medications where peak performance was

expected. This is the first study to make this comparison with subjects walking forward at a usual speed, walking forward at a fast speed, and walking backward at a safe speed. GAITRite software version 3.9 coupled with a 5 meter walkway was used at Galveston, and the VA Group 2, however GAITRite software version 3.3 was used for VA Group 1. Each site was examined individually, and then a combined Galveston and VA Group 2 was generated, to increase the sample size and thus, power to identify significant differences in gait variables.

Walking Forward Usual Speed

Velocity

Paired t-tests showed that in the current study, the mean for gait velocity was significantly higher at all sites ON medications than OFF medications. A second set of paired t-tests revealed that mean gait velocity was significantly higher on the GAITRite than over ground at all sites ON medications, and in the two VA Groups OFF medications. It should be noted that in Galveston there was no difference in gait velocity walking on the GAITRite and over ground OFF medications, but velocity was higher on the GAITRite than over ground ON medications. The low velocity seen in Galveston OFF medications may have been caused by several factors- first fatigue and stiffness from travel to Galveston, and from walking the long distance from the parking lot/curbside drop off area to the lab; second test order (where walking on the GAITRite was the first performance test) thus patients were new to the test setting and personnel; and third, patients were unfamiliar with the GAITRite and were therefore anxious about walking on an instrumented walkway. The low velocity in Galveston OFF medications obviously influenced the combined group score, where velocity on the GAITRite and over ground were not significantly different. Our findings agree, for the most part, with a

study by Bryant and colleagues. They recruited 30 subjects with PD, and had them walk on the GAITRite and over ground, both OFF and ON medications. The group demographics were as follows - 21 males, mean and standard deviation for age 68.90 ± 9.28 years, mean and standard deviation time since diagnosis 8.75 ± 5.68 years, mean H&Y stage 2.4, and all taking dopamine medication. Mean gait velocity in that sample was higher on the GAITRite than over ground, both ON & OFF PD medications (Bryant et al. 2012). Our findings are in agreement with those of Bryant and associates ON medications, and in the two VA groups OFF medications. The unusually low gait velocity in Galveston OFF medications probably caused the discrepancy in findings for Galveston and the combined Galveston – VA sites. There are several possible explanations why velocity was higher on the GAITRite than over ground. First walking on the GAITRite was a novel situation for the participants. They devoted more attention to walking on the GAITRite, and this increased attention helped them walk faster on the GAITRite. Alternatively most participants were wearing running shoes for testing and the tread of the running shoe might have gripped the floor more than the carpet of the GAITRite, thus slowing walking over ground. Returning to the question about whether measurements for velocity made on the GAITRite and over ground were the same, we did not find any significant correlations for velocity between walking on the GAITRite and over ground. This tells us that the distributions around the mean were different. At this point clinicians need to consider that measurements on the GAITRite and over ground are not equivalent for walking forward at a usual speed, and that the GAITRite values are higher.

Stride Length

Paired t-tests showed that there was no significant difference in the means for stride length, measured walking forward at a usual speed on the GAITRite and over

ground, at all sites, both ON & OFF PD medications. This might be explained by a study by Cole and colleagues, who used 3 dimensional motion analysis to evaluate gait in 49 patients with PD and 34 control subjects, and then followed them prospectively for a 1 year period, to determine the number of falls they experienced. Sixty five percent of the patients with PD reported at least one fall compared to the controls, where 50% of the subjects fell at least once. The participants were then assigned to 1 of 4 groups based on whether they had fallen or not - patients with PD fallers, patients with PD non-fallers, control subject fallers and control subject non-fallers. Gait was examined across these 4 groups. Patients with PD had increased stride time variability, walked with a more stooped posture, (lower excursions of flexion-extension in the hips and knees), and had less arm swing than the controls. The PD fallers had decreased stride length, slower gait velocity, spent longer in double limb support, and did not advance the body as far in front of the stance foot, when compared with the control subjects. Most important, participants in the PD falls group had increased mediolateral head movement, a sign of postural instability, than persons in the PD non-faller and control groups. It was suggested that if persons with PD, especially those with a history of falls, increased their gait velocity and/or stride length, they might exceed the normal limits for mediolateral head movement, and make themselves more vulnerable to falls. It is possible that patients with PD, especially those with a history of falls, limit the degree to which they increase their stride length, to avoid excessive mediolateral head movements, that could result in postural instability and potential falls (Cole et al. 2010). The subjects in our study were recruited because of a history of falls or postural instability, hence they might have self-limited their stride length to maintain stability.

There is some discrepancy between our findings and those of Bryant and associates, who reported that while mean stride length measurements between the

GAITRite and over ground were not significantly different OFF medications, they were significantly higher on the GAITRite than over ground ON medications (Bryant et al. 2012). We found no significant difference in mean stride length between the GAITRite and over ground OFF medications, but we did not see the increased mean stride length on the GAITRite ON medications. Comparing the descriptive data for stride length for the Galveston and the Bryant cohorts, stride length was similar on the GAITRite and over ground, as well as ON & OFF PD medications in the two groups (Bryant et al. 2012). Over ground, stride length was higher in the Galveston than in the Bryant cohort, ON & OFF PD medications. Since there were strong correlations between stride length and velocity, it would be inappropriate to look at a single gait parameter in isolation. Gait velocity can be higher, either due to an increase in stride length, or an increase in cadence or both. Typically, faster velocity is achieved first by an increase in stride length, and cadence remains relatively stable (Hackney et al. 2009). Once stride length capacity is maximized, cadence then increases to allow further increases in velocity (Morris et al. 2001a). As discussed earlier, stride length inadequacy is one of the most critical gait deficits in PD, and cadence has to adjust to compensate (Morris et al. 2001a). Looking at our descriptive data for Galveston in comparison with that of Bryant, several differences become evident - first, gait velocity was much lower in Galveston, both on the GAITRite and over ground OFF medications, but was equivalent to that of Bryant and associates ON medications, both on the GAITRite and over ground; second, stride length was higher over ground both OFF and ON medications in Galveston and in the Bryant sample on the GAITRite OFF and ON medications; third, cadence was lower over ground OFF and ON medications in Galveston compared to the Bryant cohort, but was similar on the GAITRite, both OFF and ON medications (Bryant et al. 2012). An explanation for why velocity might have been so low in Galveston OFF medications was offered above. As

velocity increased over ground in Galveston, participants were able to generate sufficient stride length to support the increased velocity, and took larger, but fewer steps. Comparing the Bryant and Galveston participants ON medications, gait velocity was almost identical both on GAITRite and over ground, where both groups walked faster on the GAITRite than over ground. Stride length and cadence were comparable on the GAITRite in the two cohorts ON medications. Both groups decreased velocity over ground, however the Bryant cohort decreased stride length and increased cadence, compared with the Galveston group who sustained stride length and decreased cadence. There are several possible explanations for why Galveston was able to retain the long stride length from the GAITRite even when they walked slower over ground ON medications - first, Galveston participants had lower disease severity as measured by UPDRS motor sections scores, had shorter disease duration, and were younger; second, there were more participants in Galveston who were not taking carbidopa-levodopa or dopamine agonists, and were taking rasagilene as their only PD medication; and third, Galveston had fewer participants with motor fluctuations.

Similarly for the VA Group 2 gait velocity was higher on the GAITRite but was only slightly higher over ground OFF medications than that of Bryant and colleagues; ON medications, gait velocity both on the GAITRite and over ground were much higher in the VA Group 2 compared to the Bryant participants; second stride length was slightly higher than the Bryant participants OFF medications but was much higher than Bryant's subjects ON medications; third in the VA Group 2, cadence was largely similar to that of Bryant and colleagues under all 4 conditions, and followed the same trend of being higher on the GAITRite than over ground (Bryant et al. 2012). The participants in the VA Group 2 were less involved than those in the Bryant study (Bryant et al. 2012). Gait velocity increased due to increased stride length with relatively stable cadence at the VA

Group 2. Therefore it seems likely that the VA Group 2 participants were able to increase stride length without provoking postural instability especially ON medications and did not need to tap into cadence to maintain a high velocity. The individuals in the study by Bryant and colleagues probably maximized stride length capacity and needed to compensate with increased cadence ON medications (Bryant et al. 2012).

Returning to the equivalence of measurements made on the GAITRite and over ground, even though the means for stride length were not significantly different on the GAITRite and over ground in our study, one cannot assume that the distributions around these means were the same. To this end the only significant correlations for stride length between walking on the GAITRite and over ground was at the VA Group 2 OFF medications. Therefore, with the exception of the VA Group 2 OFF medications, there is no evidence to support that measurements for stride length made on the GAITRite and over ground are the same.

Cadence

There was a significant difference in the means for cadence walking forward at a usual speed on the GAITRite and over ground OFF medications, except in Galveston, and ON medications except in the VA Group 2. Additionally, there was no significant difference in cadence ON & OFF PD medications, both on the GAITRite and over ground. It is well supported in the literature that cadence is dopamine resistant (Blin et al. 1991; Schafsma et al. 2003b). Hackney and Earhart compared forward and backward walking and found that while stride length and velocity changed, cadence remained stable (Hackney et al. 2009). Mean cadence, measured on the GAITRite and over ground was not significantly different on two occasions, first in Galveston OFF medications, and second at the VA Group 2 ON medications. In Galveston gait velocity cadence and stride length were all equivalent walking on the GAITRite and over ground OFF medications.

In the VA Group 2 ON medications, as gait velocity increased, stride length increased accordingly so that there was no need for cadence to increase. In the VA Group 1, stride length did not increase enough as gait velocity increased, so that cadence needed to make up the difference. It has been proposed that cadence can change, and it may be the way that patients with PD compensate for the deficient stride length (Morris et al. 1994).

Our results for Galveston are in agreement with those of Bryant and colleagues, who found that there was no difference in cadence measured on the GAITRite and over ground OFF medications (Bryant et al. 2012). There is a discrepancy between our findings at the VA Group 2 and those of Bryant, who found that cadence was significantly higher on the GAITRite (Bryant et al. 2012). As discussed above, the participants at the VA Group 2 had less disease severity, and were able to increase stride length as velocity increased, thus did not need to compensate with cadence as did the participants in the study by Bryant and colleagues (Bryant et al. 2012).

Walking Forward at a Fast Speed

This is the first study to examine the equivalence of walking forward at a fast speed, both on the GAITRite and over ground, as well as ON and OFF PD medications. Gait velocity walking fast forward ON medications, was always higher than gait velocity walking fast forward OFF medications, both on the GAITRite and over ground. Gait velocity on the GAITRite was higher than gait velocity over ground ON medications, and at all sites, except Galveston OFF medications. It appears that the situation in Galveston mirrors what was seen walking forward at a usual speed. The patients may have been fatigued or stiff from traveling to the lab for the GAITRite walk. Alternatively they may have experienced “test anxiety” walking on the instrumented walkway, which slowed them down. Perhaps this discrepancy was due to a measurement error walking over

ground, where it was more difficult for the examiner to count the number of steps accurately as velocity increased. It was also suggested that with increased gait velocity, it may have been more challenging for the tester to be accurate in starting and stopping the stop watch for over ground walks (Bryant et al. 2011b). While the means for velocity walking fast forward were higher on the GAITRite than over ground, the correlations for walking fast forward on the GAITRite and over ground were significant on several occasions. Distributions for velocity walking fast forward were the same for all sites ON medication, and at the VA group 1 and the combined Galveston VA2 group, OFF medications. Further research with larger samples might be warranted to determine whether the means are really different, and to see if additional significant correlations emerged for walking over ground and on the GAITRite. It was interesting that there were so many significant correlations between walking on the GAITRite and over ground, for a task that was more challenging than walking forward at a usual speed. At this point, we cannot conclude that measurements for velocity, made walking fast forward on the GAITRite and over ground were equivalent, and that velocity was higher on the GAITRite.

Walking Backward

Walking backward, the VA Group 1 was much slower, both ON & OFF PD medications, and on both walking surfaces. In fact when entering the data from the GAITRite 3.3, it was much slower, with many outlying scores. We could not access the raw data for reasons of security at the VA, so we had to use the data stored in an Access file. Without the raw data, it was difficult to trace the backward walks for each participant, hence the reliability and accuracy of the GAITRite data was questionable. Therefore we did not include this data in our discussion.

Velocity

This is the first study to examine whether the means for the gait parameters (velocity, cadence, and stride length), measured walking backward on the GAITRite and over ground are the same, both ON & OFF PD medications. Walking backward is a much more challenging task than walking forward, for patients with PD, as well as healthy elderly (Hackney et al. 2009). Individuals with PD usually show decreased velocity and stride length walking backward than forward, but there is usually little alteration of cadence between directions (Hackney et al. 2009; Bryant et al. 2011b).

Mean velocity, walking backward on the GAITRite and over ground, in either medication state, was not significantly different at all sites, with the exception of the combined Galveston VA2 group ON medications. There are several possible explanations for this. First, walking backward on the GAITRite was particularly challenging for our subjects since they could not see where they were going, needed to walk in the center of the walkway for optimal footfall recording, and finally had to utilize a toe to heel ground contact strategy with the walkway to activate the walkway sensors to record the imprint. Walking forward patients with PD are known to lose the heel to toe ground contact normally seen early in loading the leg. Similarly walking backward, especially as the stooped posture increases, patients with PD often walk more on their toes and cannot get the heel down with the leg behind, due to tight gastrocnemius and soleus muscles (Cole et al. 2010). Additionally, many participants needed to repeat trials walking backward on the GAITRite, due to insufficient acceptable footprints for analysis. With each repetition of a backward walking trial, subjects not only became more anxious but also their fear of falling, rigidity and freezing or festination of gait increased. Over ground, participants did not need to worry about path deviation and toe heel contact and were more comfortable walking without restrictions. Second, it was possible that

participants could not increase their velocity walking backward without exceeding maximal mediolateral instability of the head, thus promoting postural instability and perhaps, putting the person at risk for falling, particularly OFF medications (Cole et al. 2010). Third, the participants might not have been able to increase velocity or stride length, due to the stooped posture and inability to extend the thigh (Cole et al. 2010). Fourth, the slow velocities walking backward may have made it easier for examiners to accurately count the number of steps walking over ground, minimizing measurement error (Bryant et al. 2011b). Additionally, it may have been easier to start and stop the stop watch consistently with gait initiation and termination (Bryant et al. 2011b).

While means were not significantly different for velocity walking backward, it is essential to look at the correlations between walking backward on the GAITRite and over ground, to determine whether the distributions are the same. The only significant correlations between walking backward on the GAITRite and over ground were in Galveston ON & OFF PD medications, and in the combined Galveston VA2 group OFF medications. At this point, the data does not support that measurements for velocity made walking backward on the GAITRite and over ground, are equivalent.

Stride Length

Walking backward, measurements for stride length obtained from GAITRite and over ground walks were not significantly different ON medications, with the exception of the combined Galveston VA group. OFF medications, there was a significant difference with stride length being longer on the GAITRite at all sites. During the demonstration for walking backward on the GAITRite, participants in Galveston were instructed first to make sure that the swing leg landed beyond the stance leg, and second to make sure that they contacted the carpet with a toe heel progression. Both components of this instruction would draw the subject's attention to maximizing stride length. Walking backward over

ground, the only direction given to participants was to walk quickly and safely. Perhaps, the extra instructions given walking backward on the GAITRite in order to ensure adequate tracings, drew the participant's attention to stride length, and gave an unfair advantage to walking on the GAITRite. A possible explanation for the equivalent stride length on the GAITRite and over ground ON medications, is that participants self-limited their stride length in order to prevent excessive destabilization of the head on the trunk mediolaterally (Cole et al. 2010). Walking forward, patients with mild PD were found to have lower amplitude movement excursions at the hips and knees, as well as a more stooped posture compared with control subjects (Cole MH et al. 2010). While never evaluated walking backward, it makes sense that the stooped posture could have reduced hip excursion walking backward as well. Reduced limits of stability backward may have contributed not only to decreased stride length walking backward, but also to limited transfer of the body weight backward over the stance leg behind (Horak et al. 2005; Cole al. 2010).

Cadence

The means for cadence were significantly higher walking backward over ground than walking on the GAITRite, both ON & OFF PD medications. Variability around the means was high. None of the correlation coefficients for cadence walking on the GAITRite and over ground reached significance, indicating that the distributions were different. Probably most important, the postural challenge of walking backward resulted in such a large restriction of stride length, that increasing cadence was the only means to sustain gait velocity. The higher cadence over ground may have been caused by festination and freezing. Alternatively, participants may have wanted to please testers, and therefore used increased cadence to sustain velocity. Measurements of cadence walking on the GAITRite and over ground were not the same.

It is important to examine the inter-relationships between velocity, stride length and cadence walking backward. Starting OFF medications, mean gait velocity was not significantly different walking on the GAITRite and over ground at all sites; mean cadence was significantly higher walking over ground at all sites; mean stride length was significantly higher on the GAITRite at all sites. Switching to ON medications, mean velocity was not significantly different walking backward on the GAITRite and over ground in Galveston and the VA Group 2, but was significantly higher on the GAITRite than over ground in the combined Galveston VA2 group; mean cadence was significantly higher walking over ground than on the GAITRite at all sites; mean stride length was not significantly different walking on the GAITRite and over ground at all sites, with the exception of the combined Galveston VA group, where it was higher on the GAITRite. Even though velocity was not significantly different between walking on the GAITRite and over ground, the mechanisms used by participants to generate the velocity were different. On the GAITRite, participants generated longer stride length and therefore did not need to increase cadence as much. Over ground, the participants walked with shorter strides, and therefore needed increased cadence to sustain velocity. That stride length and cadence were both significantly different on the GAITRite and over ground exclusively OFF medications, might suggest that disease severity played a significant role, and that postural instability was at a peak. Perhaps the results were not as clear cut ON medications, due to dyskinesias that accompanied use of dopaminergic medications. An alternative explanation is that participants might have been more fatigued for ON medications testing, since it followed OFF medications testing. Stride length may have been higher on the GAITRite with the friction of the walkway reducing festination, and potentially with the additional directions to obtain favorable recording from the sensors

of the walkway. Nevertheless, velocity and stride length were lower walking backward as compared with walking forward.

LIMITATIONS TO THE STUDY

This study had some limitations that need to be addressed. First, we recruited a sample of community-dwelling individuals from local PD support groups and movement dysfunction clinics in the Houston-Galveston area. As such, there is no guarantee that our sample is representative of persons with PD in the area, and that results can be generalized to patients with PD in other areas, and to those who are not community-dwelling. One of the inclusion criteria was that participants have a history of postural instability and gait dysfunction with or without a history of falls, and be in H&Y stages 2-4. Thus it is unknown whether our findings can be generalized to patients with other types of PD (tremor, rigidity), or to patients at higher or lower H&Y stages.

The burden of ON & OFF PD testing is high and poses some limitations. The study design necessitated that OFF medication testing precede ON medications testing, so that all evaluations could be completed in a single day. This might have led to a practice effect for ON medication testing, which would have been eliminated with randomization of testing. Study design also dictated that walking on the GAITRite precede over ground walking, and that walking forward at a usual speed precede walking fast forward and walking backward. Participants might have been more fatigued during ON testing than OFF testing, thus blunting the beneficial effect of the dopamine medications. Similarly, patients might have been more fatigued walking fast forward and backward, which might have impacted performance in the latter tests. Patients were offered rest periods frequently during the testing, but the effect of fatigue is unknown, and needs to be taken

into account when interpreting the results of this study. Additionally, the evaluators were not blinded to medication state and this might limit generalizability of the findings.

When the study design was conceived, the plan was to examine the results in Galveston and in the VA groups separately, and then evaluate whether or not they were the same. If the groups were comparable, then data from the two groups was to be merged, to augment sample size and strengthen power. A problem arose for the GAITRite measurements, when it was found that the data collected on GAITRite software version 3.3 could not be merged with the data from GAITRite software versions 3.8 and 3.9. Most of the GAITRite data for participants 1-25 at the VA was collected using the older GAITRite version. Therefore, we were forced to divide the VA cohort into two and analyze the data from each group separately. This reduced the sample size for each of the two groups at the VA. With significant reduction in sample size, we may have had insufficient power to detect change in gait parameters. While we were able to confirm that calibration of the GAITRite software version 3.8 and GAITRite software version 3.9 were equivalent, it was not possible to calibrate the GAITRite software version 3.3 with the other more current GAITRite software versions. Nor were we able to test the calibration of the GAITRite 3.9 at the VA compared to the GAITRite 3.9 in Galveston. This too might limit generalizability of the study findings.

Whereas stride length measured on the GAITRite provides data for right and left legs separately, calculating stride length from timed walking with counting of the number of steps provides an average stride length of the two sides. Therefore we decided to average the GAITRite measurement for stride velocity for the left and right sides to do our correlations. It is unknown whether this method of estimation of stride length might mask the asymmetry between the two sides of the body typical of the early stages of PD.

Chapter 6 CONCLUSIONS & FUTURE DIRECTIONS

None of the balance and gait measures used in the current study were significantly correlated with the UPDRS total score or motor section score, with the exception of the PIGD index. While the UPDRS might be the gold standard to measure disease severity, it does not provide physical therapists with sufficient information on balance and gait to design individualized therapeutic interventions to optimize functional performance. As a measure of disease severity, the UPDRS focuses on the limitations of body parts (specifically tremor, rigidity, and bradykinesia), to a greater extent than limitations in activity and participation. Therapists need to evaluate what they can change, not what they cannot change. There are no known evidence-based physical therapy interventions to modify tremor, rigidity and bradykinesia.

The pull test, the single balance item on the UPDRS, measures reactive balance. This is quite different from the challenges to postural stability that are needed to perform daily living routines, which require proactive control. On the other hand, the 5 step test and turning 360 degrees are more complex measures of dynamic balance, where the participant must stabilize the head and torso while moving the body over a changing base of support. Dynamic postural stability not only requires processing the environment while moving, but also requires using feedback from the ongoing movement to plan the forthcoming movement. Requisite skills include: attention, prediction, problem solving, planning, sequencing and organizing, as well as diversifying and modulating movement to the task and environment.

The single gait item on the UPDRS qualitatively measures difficulty with walking, need for assistance, and finally, presence of shuffling short steps, festination, and propulsion. The ecological validity of the UPDRS gait item has been called into

question since it measures walking at a single speed, over an unspecified distance, and in one direction. The UPDRS gait item does not quantify the underlying spatial-temporal deficits in velocity, stride length, and cadence, that are causing difficulty walking, and that might be amenable to physical therapy interventions. Despite the large variability of walking in Parkinson's disease (PD), examination of spatial-temporal variables of gait, with the person walking at different speeds and in different directions, allows physical therapists to objectify the interaction of velocity, stride length, and cadence, as well as elucidate the movement strategies participants use under differing circumstances. Comprehending the interactions of spatial and temporal variables of gait under different walking conditions, enables physical therapists to design individualized interventions to optimize gait. Therefore, if the aims of therapy are to optimize functional mobility and activities of daily living, therapists will need to rely on examination and evaluation tools that go beyond the UPDRS.

Several of the performance balance measures, specifically the gait and balance scale (GABS) OFF medications, the postural instability gait dysfunction (PIGD) index OFF medications and turning 360 degrees to the right OFF medications were significantly correlated with the activities specific balance confidence scale (ABC), a measure of balance self-efficacy. Despite this, it is important to use both performance and self-perceived measures of balance, since they provide complementary information needed for physical therapists to design interventions that optimize postural stability and minimize falls. The physical therapist will need to use different intervention strategies for clients whose self-efficacy and balance performance are realistic and congruent, clients whose self-efficacy is lower than actual balance performance, and finally clients whose self-efficacy and actual performance are incongruent. When perception of balance confidence and actual balance performance are congruent, the role of the physical

therapist is to confirm the client's awareness of functional limits, reinforce strategies the client may have implemented on his own to maximize postural stability and minimize falls risk, and teach the client additional strategies to enable participation in activities that are meaningful and important. When perception of balance is lower than actual balance performance, the client needs to be empowered to explore functional potential under the careful guidance of a therapist with the goal of extending participation in self-care, transfers and mobility, and participation in the home or community. When the client's perception of balance confidence is exaggerated, the role of the physical therapist is to heighten the patient's and caregiver's understanding of falls risk, and consequences of falls, and teach them safer ways to participate in preferred daily tasks. Ultimately the goal is to maximize participation in self-care, mobility, and valued life roles, minimizing postural instability and risk for falls.

The constraints of today's health care delivery system make it imperative that physical therapists prioritize what is essential to evaluate in order to develop a physical therapy diagnosis, prognosis, and plan of care. This presumes elimination of redundancy in examination tests and measures. To this end, the current study offers some suggestions. Since all of the balance measures were strongly correlated ON & OFF PD medications, it may not be necessary to test in both medications states. Since turning 360 degrees to the left and right were strongly related both ON & OFF PD medications, it may not be necessary to perform 360 degree turns in both directions. The two balance tests that correlated the most with the remaining tests were the GABS and turning 360 degrees. Of the two, turning 360 degrees is much more efficient from a time management perspective. Turns of varying amplitudes are essential for carrying out most activities of daily living. Turning provokes destabilization of the head and torso mediolaterally over the moving legs; turning requires integration, coordination, and sequencing of eye head

and trunk segments; finally turning requires use of repetitive movements, which need to be modulated and updated using feedback from the ongoing movement. It may be sufficient to use timed turning 360 degrees alone, as a measure of dynamic postural stability in PD.

It is important for physical therapists to measure spatial temporal aspects of gait, in addition to observational gait analysis, when working with a patient with PD. All the therapist needs to do is have the patient walk over a given distance, first timing how long it takes to traverse the distance, and second, counting the number of steps it takes to traverse that distance, both feasible in a busy clinic. There are simple equations that allow the therapist to calculate velocity, stride length, and cadence. It is only through a consideration of the inter-relationships of the spatiotemporal variables of gait that physical therapists can make objective evidence-based decisions about what is really happening when individuals with PD walk. Therapists can objectively measure whether a patient's gait velocity is decreasing, and from that make decisions on ability to cross an intersection within the limits of a traffic light, ambulate safely in the community, ambulate safely in the household, and finally, ambulate without risk for falls. If the client's gait velocity has indeed decreased, the therapist can determine whether the decreased velocity results from decreased stride length, decreased cadence, or both. In PD if stride length is decreasing, the therapist can utilize evidence based therapy interventions, like cueing and treadmill training, to try to preserve stride length. Alternatively, the therapist needs to consider that there is a maximum for increasing velocity and stride length. If this capacity is exceeded, postural instability and increased falls risk can result, due to the resultant mediolateral instability of head movement on trunk and leg movement. If increased cadence is the cause for the increased gait velocity,

the therapist should recognize that this is usually a compensatory strategy for inadequate stride length, and that intervention is warranted.

While it would be appealing if measurements made for gait velocity, stride length, and cadence, walking on the instrumented GAITRite and over ground were the same, this was not the case. It is well known that variability is a hallmark of gait in PD, and it was indeed this large variability that prevented the measures for gait velocity, stride length and cadence, made walking on the GAITRite and over ground from being equivalent. There were even situations where the means for the gait variables (velocity, cadence and stride length) were significantly different between the GAITRite and over ground, while at the same time, the majority of the correlations walking on the GAITRite and over ground were significant. This was the case for velocity walking fast forward, and stride length walking backward, two of the more challenging walking tasks. Therapists should be cautious interpreting studies that use means to compare any gait parameter in PD. When variability around the mean is high, the mean can be misleading since it represents a single point in the distribution. It might be better to use an outcome measure that takes into account the shape of the distribution rather than a single point. It may be that correlations are more useful in determining whether measurements made on the GAITRite and over ground are equivalent.

First, future research is needed to determine the optimal distance needed to walk over ground to accurately capture steady state walking for velocity, stride length, and cadence, not only walking forward and backward at a comfortable speed, but also walking forward at a fast speed. Additionally, the optimal acceleration and deceleration time prior to and after the walk needs to be determined, so that protocols can be established to allow consistency between studies. Second, future research with large samples is needed to establish means and confidence intervals for velocity, stride length,

and cadence walking over ground. This would provide clinicians with comparisons and critical values to decide whether physical therapy interventions might be indicated first to optimize safety, and second, to maximize participation in daily activities, work, leisure activities, and life roles. Third, additional research is needed in patients with PD to determine whether deviations in gait are detected earlier walking forward at a fast speed, and walking backward, than when walking forward. Finally, additional research is needed in patients with PD about turning, specifically about amplitude of turns, and activity immediately prior to the turn. First, is there a correlation between turns of different excursions, specifically 90 degrees, 180 degrees, and 360 degrees? Second, is there a correlation between turns of different excursions, specifically 90 and 180 degrees, made from a stationary versus a walking start? Finally, is there a correlation between 90 and 180 degree turns, made from stationary and walking positions, and the other performance and self-perceived measures of balance?

Appendix A: UNIFIED PARKINSON'S DISEASE RATING SCALE

I. Mentation, Behavior and Mood

1. Intellectual Impairment

0 = None.

1 = Mild. Consistent forgetfulness with partial recollection of events and no other difficulties.

2 = Moderate memory loss, with disorientation and moderate difficulty handling complex problems. Mild but definite impairment of function at home with need for occasional prompting.

3 = Severe memory loss with disorientation for time and often to place; severe impairment in handling problems.

4 = Severe memory loss with orientation preserved to person only; unable to make judgments or solve problems; requires much help with personal care; cannot be left alone at all.

2. Thought Disorder (Due to dementia or Drug intoxication)

0 = None.

1 = Vivid Dreaming.

2 = "Benign" hallucinations with insight retained.

3 = Occasional to frequent hallucinations or delusions; without insight; could interfere with daily activities.

4 = Persistent hallucinations, delusions, or florid psychosis. Not able to care for self.

3. Depression

0 = None.

1 = Periods of sadness or guilt greater than normal, never sustained for days or weeks.

2 = Sustained depression (1 week or more).

3 = Sustained depression with vegetative symptoms (insomnia, anorexia, weight loss, loss of interest).

4 = Sustained depression with vegetative symptoms and suicidal thoughts or intent.

4. Motivation/Initiative

0 = Normal.

1 = Less assertive than usual; more passive.

2 = Loss of initiative or disinterest in elective (non-routine) activities.

3 = Loss of initiative or disinterest in day to day (routine) activities.

4 = Withdrawn, complete loss of motivation

II. Activities of Daily Living (for both “on” and “off”)

5. Speech

0 = Normal.

1 = Mildly affected. No difficulty being understood.

2 = Moderately affected. Sometimes asked to repeat statements.

3 = Severely affected. Frequently asked to repeat statements.

4 = Unintelligible most of the time.

6. Salivation

0 = Normal.

1 = Slight but definite excess of saliva in mouth; may have night time drooling.

2 = Moderately excessive saliva; may have minimal drooling.

3 = Marked excess of saliva with some drooling.

4 = Marked drooling, requires constant tissue or handkerchief.

7. Swallowing

0 = Normal.

1 = Rare choking.

2 = Occasional choking.

3 = Requires soft food.

4 = Requires "ng" tube or gastrostomy feeding.

8. Handwriting

0 = Normal.

1 = Slightly slow or small.

2 = Moderately slow or small; all words are legible.

3 = Severely affected; not all words are legible.

4 = The majority of words are not legible.

9. Cutting Food and Handling Utensils

0 = Normal.

1 = Somewhat slow and clumsy, but no help needed.

2 = Can cut most foods, although clumsy and slow; some help needed.

3 = Food must be cut by someone, but can still feed slowly.

4 = Needs to be fed.

10. Dressing

0 = Normal.

1 = Somewhat slow, but no help needed.

2 = Occasional assistance with buttoning, getting arms in sleeves.

3 = Considerable help required, but can do some things alone.

4 = Helpless.

11. Hygiene

0 = Normal.

1 = Somewhat slow, but no help needed.

2 = Needs help to shower or bathe; or very slow in hygienic care.

3 = Requires assistance for washing, brushing teeth, combing hair, going to bathroom.

4 = Foley catheter or other mechanical aids.

12. Turning in Bed and Adjusting Bed Clothes

0 = Normal.

1 = Somewhat slow and clumsy, but no help needed.

2 = Can turn alone or adjust sheets, but with great difficulty.

3 = Can initiate, but not turn or adjust sheets alone.

4 = Helpless.

13. Falling (Unrelated to Freezing)

0 = None.

1 = Rare falling.

2 = Occasionally falls, less than once per day.

3 = Falls an average of once daily.

4 = Falls more than once daily.

14. Freezing when Walking

0 = None.

1 = Rare freezing when walking; may have start hesitation.

2 = Occasional freezing when walking.

3 = Frequent freezing. Occasionally falls from freezing.

4 = Frequent falls from freezing.

15. Walking

0 = Normal.

1 = Mild difficulty. May not swing arms or may tend to drag leg.

2 = Moderate difficulty, but requires little or no assistance.

3 = Severe disturbance of walking, requiring assistance.

4 = Cannot walk at all, even with assistance.

16. Tremor (Symptomatic complaint of tremor in any part of body.)

0 = Absent.

1 = Slight and infrequently present.

2 = Moderate; bothersome to patient.

3 = Severe; interferes with many activities.

4 = Marked; interferes with most activities.

17. Sensory Complaints Related to Parkinsonism

0 = None.

1 = Occasionally has numbness, tingling, or mild aching.

2 = Frequently has numbness, tingling, or aching; not distressing.

3 = Frequent painful sensations.

4 = Excruciating pain.

III. Motor Examination

18. Speech

0 = Normal.

1 = Slight loss of expression, diction and/or volume.

2 = Monotone, slurred but understandable; moderately impaired.

3 = Marked impairment, difficult to understand.

4 = Unintelligible.

19. Facial Expression

0 = Normal.

1 = Minimal hypomimia, could be normal “poker face.”

2 = Slight but definitely abnormal diminution of facial expression.

3 = Moderate hypomimia; lips parted some of the time.

4 = Masked or fixed faces with severe or complete loss of facial expression; lips parted 1/4 inch or more.

20. Tremor at Rest (head, upper and lower extremities)

0 = Absent.

1 = Slight and infrequently present.

2 = Mild in amplitude and persistent. Or moderate in amplitude, but only intermittently present.

3 = Moderate in amplitude and present most of the time.

4 = Marked in amplitude and present most of the time.

21. Action or Postural Tremor of Hands

0 = Absent.

1 = Slight; present with action.

2 = Moderate in amplitude, present with action.

3 = Moderate in amplitude with posture holding as well as action.

4 = Marked in amplitude; interferes with feeding.

22. Rigidity (Judged on passive movement of major joints with patient relaxed in sitting position. Cogwheeling to be ignored.)

0 = Absent.

1 = Slight or detectable only when activated by mirror or other movements.

- 2 = Mild to moderate.
- 3 = Marked, but full range of motion easily achieved.
- 4 = Severe, range of motion achieved with difficulty.

23. Finger Taps (Patient taps thumb with index finger in rapid succession.)

- 0 = Normal.
- 1 = Mild slowing and/or reduction in amplitude.
- 2 = Moderately impaired. Definite and early fatiguing. May have occasional arrests in movement.
- 3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement.
- 4 = Can barely perform the task.

24. Hand Movements (Patient opens and closes hands in rapid succession.)

- 0 = Normal.
- 1 = Mild slowing and/or reduction in amplitude.
- 2 = Moderately impaired. Definite and early fatiguing. May have occasional arrests in movement.
- 3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement.
- 4 = Can barely perform the task.

25. Rapid Alternating Movements of Hands (Pronation-supination movements of hands, vertically and horizontally, with as large an amplitude as possible, both hands simultaneously.)

- 0 = Normal.
- 1 = Mild slowing and/or reduction in amplitude.
- 2 = Moderately impaired. Definite and early fatiguing. May have occasional arrests in movement.
- 3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement.
- 4 = Can barely perform the task.

26. Leg Agility (Patient taps heel on the ground in rapid succession picking up entire leg. Amplitude should be at least 3 inches.)

- 0 = Normal.
- 1 = Mild slowing and/or reduction in amplitude.
- 2 = Moderately impaired. Definite and early fatiguing. May have occasional arrests in movement.
- 3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement.
- 4 = Can barely perform the task.

27. Arising from Chair (Patient attempts to rise from a straight-backed chair, with arms folded across chest.)

0 = Normal.

1 = Slow; or may need more than one attempt.

2 = Pushes self-up from arms of seat.

3 = Tends to fall back and may have to try more than one time, but can get up without help.

4 = Unable to arise without help.

28. Posture

0 = Normal erect.

1 = Not quite erect, slightly stooped posture; could be normal for older person.

2 = Moderately stooped posture, definitely abnormal; can be slightly leaning to one side.

3 = Severely stooped posture with kyphosis; can be moderately leaning to one side.

4 = Marked flexion with extreme abnormality of posture.

29. Gait

0 = Normal.

1 = Walks slowly, may shuffle with short steps, but no festination (hastening steps) or propulsion.

2 = Walks with difficulty, but requires little or no assistance; may have some festination, short steps, or propulsion.

3 = Severe disturbance of gait, requiring assistance.

4 = Cannot walk at all, even with assistance.

30. Postural Stability (Response to sudden, strong posterior displacement produced by pull on shoulders while patient erect with eyes open and feet slightly apart. Patient is prepared.)

0 = Normal.

1 = Retropulsion, but recovers unaided.

2 = Absence of postural response; would fall if not caught by examiner.

3 = Very unstable, tends to lose balance spontaneously.

4 = Unable to stand without assistance.

31. Body Bradykinesia and Hypokinesia (Combining slowness, hesitancy, decreased arm swing, small amplitude, and poverty of movement in general.)

0 = None.

1 = Minimal slowness, giving movement a deliberate character; could be normal for some persons. Possibly reduced amplitude.

2 = Mild degree of slowness and poverty of movement which is definitely abnormal. Alternatively, some reduced amplitude.

3 = Moderate slowness, poverty or small amplitude of movement.

4 = Marked slowness, poverty or small amplitude of movement.

IV. Complications of Therapy

(In the past week)

A. Dyskinesias

32. Duration: What proportion of the waking day are dyskinesias present?

(Historical information.)

0 = None

1 = 1–25% of day.

2 = 26–50% of day.

3 = 51–75% of day.

4 = 76–100% of day.

33. Disability: How disabling are the dyskinesias?

(Historical information; may be modified by office examination.)

0 = Not disabling.

1 = Mildly disabling.

2 = Moderately disabling.

3 = Severely disabling.

4 = Completely disabled.

34. Painful Dyskinesias: How painful are the dyskinesias?

0 = No painful dyskinesias.

1 = Slight.

2 = Moderate.

3 = Severe.

4 = Marked.

35. Presence of Early Morning Dystonia

0 = No

1 = Yes

B. Clinical Fluctuations

36. Are “off” periods predictable?

0 = No

1 = Yes

37. Are “off” periods unpredictable?

0 = No

1 = Yes

38. Do “off” periods come on suddenly, within a few seconds?

0 = No

1 = Yes

39. What proportion of the waking day is the patient “off” on average?

0 = None

1 = 1–25% of day.

2 = 26–50% of day.

3 = 51–75% of day.

4 = 76–100% of day.

C. Other Complications

40. Does the patient have anorexia, nausea, or vomiting?

0 = No

1 = Yes

41. Any sleep disturbances, such as insomnia or hypersomnolence?

0 = No

1 = Yes

42. Does the patient have symptomatic orthostasis?

(Record the patient’s blood pressure, height and weight on the scoring form)

0 = No

1 = Yes

V. Modified Hoehn and Yahr Staging

STAGE 0 = No signs of disease.

STAGE 1 = Unilateral disease.

STAGE 1.5 = Unilateral plus axial involvement.

STAGE 2 = Bilateral disease, without impairment of balance.

STAGE 2.5 = Mild bilateral disease, with recovery on pull test.

STAGE 3 = Mild to moderate bilateral disease; some postural instability; physically independent.

STAGE 4 = Severe disability; still able to walk or stand unassisted.

STAGE 5 = Wheelchair bound or bedridden unless aided.

VI. Schwab and England Activities of Daily Living Scale

100% = Completely independent. Able to do all chores without slowness, difficulty or impairment. Essentially normal. Unaware of any difficulty.

90% = Completely independent. Able to do all chores with some degree of slowness, difficulty and impairment. Might take twice as long. Beginning to be aware of difficulty.

80% = Completely independent in most chores. Takes twice as long. Conscious of difficulty and slowness.

70% = Not completely independent. More difficulty with some chores. Three to four times as long in some. Must spend a large part of the day with chores.

60% = Some dependency. Can do most chores, but exceedingly slowly and with much effort. Errors; some impossible.

50% = More dependent. Help with half, slower, etc. Difficulty with everything.

40% = Very dependent. Can assist with all chores, but few alone.

30% = With effort, now and then does a few chores alone or begins alone. Much help needed.

20% = Nothing alone. Can be a slight help with some chores; severe invalid.

10% = Totally dependent, helpless; complete invalid.

0% = Vegetative functions such as swallowing, bladder and bowel functions are not functioning, bedridden.

Fahn S, Elton R, Members of the UPDRS Development Committee. (1987). In: Fahn, S, Marsden, C. D., Calne, D. B , Goldstein, M, (Eds.), *Recent developments in Parkinson's disease* (pp. 153-163,293-304). Florham Park, NJ: Macmillan Health Care Information.

Appendix B GAIT AND BALANCE SCALE (GABS)

Subject ID _____ Date _____ Pre ____ Post ____ 6 month

<p>1. Level of care</p> <p>0 = entirely independent 1 = requires minimal assistance in only a few activities 2 = requires moderate assistance in several activities 3 = requires assistance frequently with most activities 4 = entirely dependent on nearly all ADL's, nursing care</p>
<p>2. Walking environment</p> <p>0 = able to walk anywhere, able to negotiate any terrain 1 = walks only in the immediate neighborhood, able to walk up and down gentle hills 2 = walks only in the driveway, avoids uneven surface and hills 3 = walks inside the house only 4 = unable to walk even at home</p>
<p>3. Ambulation (UPDRS item)</p> <p>0 = normal 1 = mild difficulty, requires no assistance 2 = independent with a cane or walker 3 = severe limitation, requires assistance besides a cane or walker 4 = unable to ambulate even with assistance, wheel-chair bound or bedridden</p>
<p>4. Falls</p> <p>0 = no falls 1 = rare falls (< 1 per month) 2 = falls ≥ 1 per month 3 = falls ≥ 1 per week 4 = falls ≥ 1 per day</p>
<p>5. Limitation of activity due to fear of falling</p> <p>0 = no limitation 1 = able to ambulate independently, but with caution 2 = usually holds on during walking, shower, or dressing 3 = rarely ventures outside the house because of fear of falling 4 = does not even attempt to stand or walk because of fear of falling</p>
<p>6. Freezing (UPDRS Item)</p> <p>0 = no freezing 1 = occasional start hesitation 2 = freezes ≥ 1 per week 3 = freezes ≥ 1 per day, occasionally falls 4 = unable to ambulate due to freezing, frequent falls</p>
<p>7. Freezing -modifying factors (UPDRS item)</p> <p>0 = no freezing 1 = only occasionally when initiating gait, turning, walking through narrow passages, or reaching a destination 2 = more than 25% when initiating gait, turning, walking through narrow passages, or reaching a destination 3 = more than 50% when initiating gait, turning, walking through narrow passages, or reaching a destination 4 = most of the time (more than 75%)</p>
<p>SUB SCORE OF ITEMS 1 – 7 _____</p>

<p>8. Rising from a chair (<i>patient attempts to arise from a straight-back wood or metal chair with arms folded across chest</i>) (UPDRS item)</p> <p>0 = normal 1 = slow; may need more than one attempt 2 = pushes self-up from arms of seat 3 = tends to fall back and may have to try more than once, but can get up without help 4 = unable to arise without help</p>
<p>9. Posture (UPDRS item)</p> <p>0 = normal 1 = not quite erect, slightly stooped posture; could be normal for older person 2 = moderately stooped posture, definitely abnormal; can be slightly leaning to one side 3 = severely stooped posture with kyphosis; can be moderately leaning to one side 4 = marked flexion with extreme abnormality of posture</p>
<p>10. Postural stability (UPDRS item) (<i>response to sudden posterior displacement produced by pull on shoulders while patient erect and prepared with eyes open and feet slightly apart</i>)</p> <p>0 = normal 1 = retropulsion, but recovers unaided 2 = absence of postural response, would fall if not caught by examiner 3 = very unstable, tends to lose balance spontaneously 4 = unable to stand without assistance</p>
<p>11. Balance during stance (BBS item)(feet close together with eyes open)</p> <p>0 = no impairment 1 = increased sway, but can stand with feet together 2 = cannot stand with feet together, but able to stand with widened stance 3 = balance is tenuous regardless of stance or foot position 4 = cannot stand >10 s without assistance or support.</p>
<p>12. Romberg test (BBS item) (<i>with eyes closed</i>)</p> <p>0 = no difficulty, > 20 s 1 = mild difficulty, 10–20 s 2 = moderate difficulty, 5–10 s 3 = severe, < 5 s 4 = unable to stand without support</p>
<p>13. One limb stance (BBS item)</p> <p>0 = no difficulty, > 20 s 1 = mild difficulty, 10–20 s 2 = moderate difficulty, 5–10 s 3 = severe, < 5 s 4 = unable to do single stance</p>
<p>14. Tandem stance (BBS item)</p> <p>0 = no difficulty, > 20 s 1 = mild difficulty, 10–20 s 2 = moderate difficulty, 5–10 s 3 = severe, < 5 s 4 = unable to do single stance</p>
<p>15. Gait (UPDRS item) (<i>walking 5 m</i>)</p> <p>0 = normal 1 = walks slowly, may shuffle with short steps, decreased arm swing 2 = walks with difficulty, but requires little or no assistance; may have some festination, short steps, or propulsion 3 = severe disturbance of gait, requiring assistance 4 = cannot walk at all, even with assistance</p>

<p>16. Turning 180° after walking</p> <p>0 = normal pivoting 1 = takes an extra step or two to turn, but no freezing or problems with balance 2 = turns en bloc, occasional freezing 3 = able to turn but requires minimal assistance 4 = unable to turn without full assistance</p>
<p>17. Turning 360° (BBS item) (<i>turn completely around in a full circle, pause, and then turn a full circle in the other direction</i>)</p> <p>0 = able to turn 360° in both directions, ≤ 4 s per turn 1 = able to turn 360° safely only in one direction, ≤ 4 s per turn 2 = able to turn 360° safely but slowly, > 4 s per turn 3 = needs close supervision or verbal cuing 4 = needs assistance while turning</p>
<p>18. Walking on heels</p> <p>0 = normal 1 = impaired 2 = unable</p>
<p>19. Walking on toes</p> <p>0 = normal 1 = impaired 2 = unable</p>
<p>20. Walking in tandem</p> <p>0 = normal 1 = impaired 2 = unable</p>
<p>21. Arm swing (<i>vertical wrist displacement</i>)</p> <p>0 = normal 1 = reduced 2 = absent</p>
<p>22. Provocative test for freezing, motor blocks (<i>rise from a chair and walk 5 m, between two chairs spaced 24 in. apart, turn 180°, walk back and sit down</i>)</p> <p>(a) Start hesitation</p> <p>0 = No 1 = Yes</p> <p>(b) Sudden transient blocks interrupting gait</p> <p>0 = No 1 = Yes</p> <p>(c) Motor blocks on turning</p> <p>0 = No 1 = Yes</p> <p>(d) Motor blocks on reaching a target (chair)</p> <p>0 = No 1 = Yes</p> <p>(e) Motor blocks when walking through narrow spaces (24 inches)</p> <p>0 = No 1 = Yes</p>
<p>23. Functional reach _____ Inches</p> <p>0 = Normal (≥ 10 in) 1 = Impaired (< 10 in)</p>
<p>24. Modified Tinetti Gait Evaluation (POMA gait item) (<i>Total score 0–12; Examine patient while walking a 10 m distance including a turn</i>)</p>

<p>(a) Initiation of gait 0 = No hesitancy 1 = Any hesitancy or multiple attempts to start</p> <p>(b) Step length and height i) Right swing foot 0 = Passes left stance foot 1 = Does not pass left stance foot with step ii) Right foot 0 = Completely clears floor 1 = Does not clear floor completely with step iii) Left swing foot 0 = Passes right stance foot 1 = Does not pass right stance foot with step iv) Left foot 0 = Completely clears floor 1 = Does not clear floor completely with step</p> <p>(c) Step symmetry 0 = Right and left step appear equal 1 = Right and left step length not equal (estimate)</p> <p>(d) Step continuity and rhythmicity 0 = Steps appear continuous 1 = Stopping or discontinuity between steps</p> <p>(e) Path (<i>estimated in relation to floor tiles, 12-in. diameter; observe excursion of one foot over about 5 m of the course</i>) 0 = Straight without walking aid 1 = Mild or moderate deviation or uses walking aid 2 = Marked deviation</p> <p>(f) Trunk 0 = No sway, no flexion, no use of arms, and no use of walking aid 1 = No sway but flexion of knees back or spreads arms 2 = Marked sway or uses walking aid</p> <p>(g) Walking distance 0 = Heels almost touching while walking 1 = Heels apart</p>
<p>25. Foam Posturography (<i>stand barefooted with eyes closed on a 5 inch, medium density foam pad for 15 s</i>) 0 = yes 1 = no</p>
<p>SUB SCORE OF ITEMS 8 – 25 _____</p>
<p>TOTAL SCORE FOR ALL THE ITEMS 1–25 _____</p>

Non-scored section of GABS

Appendix C The Activities-specific Balance Confidence (ABC) Scale*

Instructions to Participants:

For each of the following, please indicate your level of confidence in doing the activity without losing your balance or becoming unsteady from choosing one of the percentage points on the scale from 0% to 100%. If you do not currently do the activity in question, try and imagine how confident you would be if you had to do the activity. If you normally use a walking aid to do the activity or hold onto someone, rate your confidence as it you were using these supports. If you have any questions about answering any of these items, please ask the administrator.

The Activities-specific Balance Confidence (ABC) Scale

For each of the following activities, please indicate your level of self-confidence by choosing a corresponding number from the following rating scale:

0% 10 20 30 40 50 60 70 80 90 100%
no confidence completely confident

“How confident are you that you will not lose your balance or become unsteady when you...

1. ...walk around the house? ____%
2. ...walk up or down stairs? ____%
3. ...bend over and pick up a slipper from the front of a closet floor ____%
4. ...reach for a small can off a shelf at eye level? ____%
5. ...stand on your tiptoes and reach for something above your head? ____%
6. ...stand on a chair and reach for something? ____%
7. ...sweep the floor? ____%
8. ...walk outside the house to a car parked in the Driveway? ____%
9. ...get into or out of a car? ____%
10. ...walk across a parking lot to the mall? ____%
11. ...walk up or down a ramp? ____%
12. ...walk in a crowded mall where people rapidly walk past you? ____%
13. ...are bumped into by people as you walk through the mall? ____%
14. ... step onto or off an escalator while you are holding onto a railing? ____%
15. ... step onto or off an escalator while holding onto parcels such that you cannot hold onto the railing? ____%
16. ...walk outside on icy sidewalks? ____%

*Powell, L. E. & Myers, A. M. The Activities-specific Balance Confidence (ABC) Scale. *J Gerontol Med Sci*, 50, M28-34

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- B. NIH RO1 Grant number HD051844 2006-2012, Elizabeth J. Protas, PhD, & Eugene C, Lai, Co-Principle Investigators.
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COMMITTEE RESPONSIBILITIES:

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 - b. American Physical Therapy Association, Treasurer, Section for Neurology, 1997-1999
 - c. American Physical Therapy Association, President, Section for Aquatics 1999-2001,
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B. UTMB

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TEACHING RESPONSIBILITIES AT UTMB- School of Health Professions:

- a. PHYT 6225: Psychosocial Aspects of Disability, 2004-2009, Primary Instructor.
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- d. PHYT 6467: Diagnosis and Management in Neuromuscular Dysfunction II, 2004-2007, Adjunct in Instruction.

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- c. Best Faculty Award Drexel University, 2003.

PUBLICATIONS (peer reviewed journals):

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