COMPARISON BETWEEN FORWARD AND BACKWARD GAIT RETRAINING FOR MOBILITY IN INDIVIDUALS WITH MILD TO MODERATE PARKINSON'S DISEASE

by

Roné Grobbelaar

Article-format MSc

Thesis presented in partial fulfilment of the requirements for the degree of Master of Science in the Faculty of Education at Stellenbosch University

Supervisor: Dr Karen Welman

Co-supervisor: Prof Ranel Venter

March 2017

Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

March 2017

ABSTRACT

Background

Dysfunctional gait and transitional movements are the most disabling features of Parkinson's disease (PD) and often relates to falls. Due to executive dysfunction in PD, dual tasking (DT) is detrimental to already impaired mobility parameters. Backwards walking (BW) might be a useful training alternative to improve aberrant PD gait and transitional movements to consequently improve the quality of complex, multi-directional daily activities, which most often involve DT. Over ground BW gait retraining has shown to be beneficial for neurological gait rehabilitation; however, has not yet been investigated in PD. Training in complex, novel tasks may induce enhanced cortical activity for movement preparation that is beyond training in automatic tasks.

Purpose

This study aimed to compare the effect of an eight-week forward and backwards gait retraining program on gait parameters, postural transitions and turning in PD individuals as well as the related percentage DT interference (%DTC).

Methods

This randomized controlled trial was performed as a staggered design in the Western Cape. Twenty-nine PD individuals (34.5% women) with disease severity of 38.1±12.3 (Movement Disorder Society – Unified Parkinson's Disease Rating Scale; UPDRS III) were randomly assigned into a forward (FWG) or backward (BWG) walking group by means of concealed, simple randomization (1:1 ratio). The FWG included 14 participants (aged: 70±11 years; Hoehn and Yahr (H&Y): 2.7±0.5; disease duration: 7±6 years) and was compared to 15 participants of similar age (72±6 years), H&Y (2.7±0.9) and disease duration (5±3 years) in the BWG. Groups performed a 24-session (3x/week for eight weeks) over ground gait retraining program of the same tasks in opposite directions. Descriptive measures at baseline included body mass index, experiences of daily living (UPDRS II), global cognition (Montreal Cognitive Assessment), depression (Patient Health Questionnaire-9) and freezing status (Freezing of Gait Questionnaire). Participants completed an instrumented (APDM®) 10m-Walk (i10mWT), a Five-times-Sit-to-Stand (i5xSTS) and Timed-Up-and-Go (iTUG) test under both single task (ST) and DT (cognitive, arrhythmic) conditions before and after the intervention. Participants were blinded to the primary outcome measures, which were selected gait variables (i10mWT), sit-to-stand (i5xSTS) and stand-to-sit (iTUG) transitions as well as turning variables (iTUG), together with %DTC of each variable. Secondary outcome measures included functional capacity (FC, Six-

Minute-Walk test), balance confidence (Activity-specific Balance Confidence scale) and disease related quality of life (Parkinson's Disease Questionnaire-39; PDQ-39).

Results

Both groups improved ST walking velocity (FWG: p=0.04, d=0.35; BWG: p<0.01, d=0.57), ST turning velocity (FWG: p=0.04, d=0.28; BWG: p=0.05, d=0.28), FC (FWG: d=0.82; BWG: d=1.06; p<0.01) and MDS-UPDRS III scores (FWG: p=0.02, d=0.45; BWG: p=0.03, d=0.62). Additionally, the BWG improved individual PDQ-39 domains (p=0.01, d=0.41), i10mWTST time (p<0.01, d=0.45), gait cycle time (p=0.01, d=0.00), stride length (SL; p=0.02, d=0.39) and cadence (p<0.01, d=0.67); however worsened SL variability (p=0.04, d=0.83) under ST conditions. The BWG also improved %DTC for percentage double support (%DS) variability (p=0.05, d=0.57); however deteriorated %DTC for %DS (p=0.05, d=0.45) and swing time gait asymmetry (p=0.02, d=0.61). The FWG improved UPDRS II scores (p=0.03, d=0.44), i5xSTSST duration (p<0.01, d=0.52), iTUG duration (ST: p<0.01, d=0.71; DT: p=0.02, d=0.54), turning angle (ST: p=0.02, d=0.52; DT: p=0.01, d=0.62) and %DTC for SL (p=0.02, d=0.67).

Conclusion

Both FW and BW over ground gait retraining can be beneficial for PD mobility. Even though most outcomes are training direction specific, findings illustrates that the ability to learn remains intact in mild to moderate PD. Considering that both interventions yielded individual benefits, BW should not replace, but rather be added to a FW gait retraining program. Albeit FW can be a beneficial non-pharmacological method to improve mobility aspects, BW is an interesting alternative for rehabilitative purposes in mild to moderate PD.

OPSOMMING

Agtergrond

Disfunksionele loopgang en oorgangsbewegings is die mees belemmerende kenmerke van Parkinson se siekte (PD) en hou dikwels verband met valrisiko. Te danke aan verswakte uitvoerende funksie in PD, word mobiliteit verder belemmer wanneer ’n dubbele-taak (DT) bygevoeg word. Agteruit loop (BW) kan 'n nuttige alternatief vir rehabilitasie van abnormale loopgang en oorgang bewegings in PD wees. Sodoende, kan die gehalte van komplekse, multi-rigting daaglikse aktiwiteite, wat meestal DT insluit, verbeter word. Voorheen is getoon dat inoefening van bogrondse BW vir loopgang in neurologiese kondisies voordelig kan wees, maar is egter nog nie in PD ondersoek nie. In vergelyking met inoefening van ’n bekende, outomatiese taak, kan inoefening van ’n komplekse, nuwe taak verbeterde kortikale aktiwiteit vir voorbereiding van beweging veroorsaak.

Doel

Die doel van hierdie studie was om 'n agt-weke vorentoe en agtertoe loopgang inoefeningsprogram in PD individue te vergelyk ten opsigte van loopgang veranderlikes, posturale oorgangsbewegings en draai vermoëns sowel as die verwante invloed van ’n DT (%DTC) op hierdie veranderlikes.

Metodes

Hierdie studie is as 'n gespreide ontwerp in die Wes-Kaap uitgevoer, waar groepe, insluitend ’n kontrole groep, lukraak verdeel was. Nege-en-twintig PD individue (34,5% vroue) met siekte ernstigheidsgraad van 38.1 ± 12.3 (Movement Disorder Society – Unified Parkinson’s Disease Rating Scale; UPDRS III) is ewekansig verdeel in 'n vorentoe (FWG) of agtertoe (BWG) loop groep deur middel van versteekte, eenvoudige randomisering (1: 1-verhouding). Die FWG het 14 deelnemers (ouderdom: 70±11 jaar; Hoehn en Yahr (H&Y): 2.7±0.5; siekte duur: 7 ± 6 jaar) ingesluit en is met 15 deelnemers van dieselfde ouderdom (72±6 jaar), H&Y (2.7±0.9) en siekte duur (5 ± 3 jaar) in die BWG vergelyk. Groepe het 'n 24-sessie (3x / week vir agt weke) bogrondse loopgang inoefeningsprogram, van dieselfde take in teenoorgestelde rigtings, gevolg. Beskrywende veranderlikes by basislyn het liggaamsmassa-indeks, ervarings van die daaglikse lewe (UPDRS II), globale kognisie (Montreal Cognitive Assessment), depressie (Patient Health Questionnaire-9) en vries-status (Freezing of Gait Questionnaire) ingesluit. Deelnemers het 'n instrumentele (APDM®) 10m-Stap (i10mWT), 'n Vyf-Keer-Sit-tot-Staan (i5xSTS) en Staan-Op-en-Gaan (iTUG) toets onder beide enkel-taak (ST) en DT (kognitiewe, aritmiese) toestande voor

en na die intervensie voltooi. Deelnemers was geblind teen die primêre uitkomsveranderlikes, wat loopgang (i10mWT), sit-tot-staan (i5xSTS) en staan-tot-sit (iTUG) bewegings sowel as draai veranderlikes (iTUG) insluit, tesame met %DTC van elke veranderlike. Sekondêre uitkomsveranderlikes het funksionele kapasiteit (Ses-Minute-Stap toets), balans selfvertroue (Activity-specific Balance Confidence skaal) en siekte-verwante kwaliteit van lewe (Parkinson's Disease Questionnaire-39; PDQ-39) ingesluit.

Resultate

Beide groepe het ST loopgang spoed (FWG: p=0.04, d=0.35; BWG: p<0.01, d=0.57), ST draai spoed (FWG: p=0.04, d=0.28; BWG: p=0.05, d=0.28), funksionele kapasiteit (FWG: d=0.82; BWG: d=1.06; p<0.01) en MDS-UPDRS III tellings (FWG: p=0.02, d=0.45; BWG: p=0.03, d=0.62) verbeter. Addisioneel het die BWG individuele PDQ-39 domeine (p=0.01, d=0.41), $i10mWT^{ST}$ tyd (p<0.01, d=0.45), loopgang siklus tyd (p=0.01, d=0.00), tree lengte (SL; p=0.02, d=0.39) en tree frekwensie (p<0.01, d=0.67) verbeter, maar egter SL variasie (p=0.04, d=0.83) onder ST toestande verswak. Die BWG het ook %DTC vir persentasie dubbel-ondersteuning (%DS) variasie (p=0.05, d=0.57) verbeter, maar egter %DTC vir %DS (p=0.05, d=0.45) en swaai-tyd loopgangasimmetrie (p=0.02, d=0.61) verswak. Die FWG het UPDRS II tellings (p=0.03, d=0.44), $i5xSTS^{ST}$ tyd (p<0.01, d=0.52), iTUG tyd (ST: p<0.01, d=0.71; DT: p=0.02, d=0.54), draai hoek (ST: p=0.02, d=0.52; DT: p=0.01, d=0.62) en %DTC vir SL (p=0.02; d=0.67) verbeter.

Afsluiting

Beide vorentoe en agteruit bogrondse loopgang inoefening kan voordelig vir mobiliteit in PD wees. Selfs al is die meeste uitkomsveranderlikes rigting spesifiek, het bevindinge geïllustreer dat die vermoë om te leer ongeskonde in ligte tot matige PD bly. In ag genome dat beide intervensies individuele voordele opgelewer het, moet BW nie FW in rehabilitasie vervang nie, maar eerder addisioneel by FW loopgang inoefening gevoeg word. Alhoewel FW 'n effektiewe nie-farmakologiese metode om aspekte van mobiliteit te verbeter is, is BW 'n interessante alternatief vir rehabilitasie in ligte tot matige PD.

ACKNOWLEDGEMENTS

This research project would not have been possible without the moral, emotional and physical support from a variety of entities. I am thankful for each and every one who contributed in some way to make this thesis a success.

I am sincerely grateful for my supervisor, Dr Karen Welman, for her assistance, support and aspiring guidance throughout the past year during the preparation and execution of my thesis. I appreciate your patients, motivation and immense insights and knowledge with the greatest respect and admiration. Without your expert supervision and constant help, this thesis would not have been possible.

I would like to express my deepest appreciation to my co-supervisor, Prof Ranel Venter, for sharing her pearls of wisdom during the course of the research. I am grateful for your insights on my manuscripts.

Special thanks to Elizma Atterbury for her assistance as instructor for some of the exercise sessions as well as her research insights. Your enthusiasm, spirit and willingness to help are contagious, inspiring and absolutely commendable.

I express my warm thanks to Prof Martin Kidd, for his assistance in the statistical analysis of this project. I appreciate your friendly willingness to help.

I am indebted to all the participants of the study as well as their companions who so frequently joined, for their precious time, continuous enthusiasm and good spirit during the course of the study. My study would not have been possible without your effort.

I thank the Department of Sport Science – Movement Lab of Stellenbosch University as well as the National Research Foundation for their financial support in the research.

I would like to thank my family and friends, who supported me throughout the entire process of my thesis. I sincerely appreciate your unconditional love and motivation for me to strive towards my goals.

I am grateful for God who provided me with good health and wellbeing as well as the strength that carried me through tough times. Lesson learned and experiences gained during this project definitely shaped me for the future.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ABBREVIATIONS

ABC	:	Activity-specific balance confidence
ADL	:	Activities of daily living
BW	:	Backwards walking
BWG	:	Backwards walking group
DOMS	:	Delayed onset of muscle soreness
DTC	:	Dual task cost
ES	:	Effect size
FC	:	Functional capacity
FWG	:	Forward walking group
FOG	:	Freezing of gait
FOG-Q	:	Freezing of gait questionnaire
FW	:	Forward walking
GA	:	Gait asymmetry
GC	:	Gait cycle
HR	:	Heart rate
H&Y	:	Hoehn and Yahr stage
ICC	:	Intra-rater intraclass correlation coefficients
MDS	:	Movement Disorder Society
MDS-UPDRS	:	Movement Disorder Society Unified Parkinson's disease rating scale
PDQ	:	Parkinson's disease quality of life questionnaire
PD	:	Parkinson's disease

PIGD	:	Postural instability and gait difficulty
QoL	:	Quality of life
ROM	:	Range of motion
SMA	:	Supplementary motor area
SL	:	Stride length
SSA	:	Sub-Saharan African
SV	:	Stride velocity
TD	:	Tremor dominant
TUG	:	Timed-up-and-go test
UPDRS	:	Unified Parkinson's disease rating scale
6MWT	:	Six-minute walk test
5xSTS	:	Five-Times-Sit-to-Stand test

DEFINITIONS OF KEY TERMINOLOGY

Activities of daily living is an umbrella term for activities and tasks that individuals routinely perform during their everyday life (Fricke 2010).

Axial deficits can be defined as "non-optimal movement occurring in any aspect of the axial areas of the body, such as the head, shoulders, trunk and pelvis" (Hulbert et al. 2014, p. 2).

Bradykinesia is defined as the slowness and reduction of movement (Cole et al. 2010).

Cadence, or step rate, is the number of steps per minute (step/min) (Salarian et al. 2010).

Centre of gravity is the theoretical point around which the forces of gravity are completely balanced and, in humans, it is located in the pelvic region (Laufer 2005).

Cognitive motor interventions refer to training regimens where a cognitive task and motor task is performed simultaneously (Wang et al. 2016).

Double-limb support refers to the two periods during a single gait cycle where both feet are in contact with the ground simultaneously (Salarian et al. 2010).

Dual tasking occurs when an individual performs two tasks, which can be motor or cognitive, simultaneously whilst dividing attention between the two tasks (Yogev-Seligmann et al. 2008).

Dynamic balance in PD is characterized by maintaining stability when transferring from one position to another (Protas et al. 2005).

Executive function is defined as a set of higher order cognitive processes that control, integrate, organise and maintain several other cognitive abilities for goal-directed behaviour (King et al. 2015).

A **fall** is defined as an "event which results in a person unintentionally coming to rest on the ground or other level, not as the result of a major intrinsic event or overwhelming hazard" (Almeida et al. 2014, p. 2).

Freezing of gait is a disorder in which individuals experience a transient inability to initiate or continue effective locomotion (Peterson et al. 2012).

Functional capacity gives an indication of an individual's ability to perform independent daily activities that require sustained aerobic metabolism (Arena et al. 2007; Sugiura et al. 2016)

Gait refers to the act and manner of walking or running (Eisenberg 1995).

Gait asymmetry in the lower extremities is defined as the bilateral coordination of the timing of swing durations during gait, i.e. the swing times of one leg compared to the swing time of the contra-lateral leg (Yogev-Seligmann et al. 2008).

A forward **gait cycle** refers to the sequence of events that occur between successive heel contacts of the same foot (Schaafsma et al. 2003).

Gait hypokinesia is produced when the feet barely leave the ground and results in short, quick steps, resulting in a shuffle walking pattern (Bello et al. 2014).

Gait variability refers to the variability seen in spatiotemporal gait parameters and is presented as the coefficient of variation of a specific parameter (Albani et al. 2014).

Idiopathic PD refers to Parkinsonism with no external identifiable cause (Nagal & Singla 2016).

Kinaesthetic awareness refers to the ability to consciously obtain information from receptors in muscles and tendons about the rates of movement (Johnson & Soucacos 2010). See proprioception.

Mild to moderate Parkinson's refers to a severity level of I to III on the Hoehn and Yahr rating scale (Nagal & Singla 2016). More specifically, a disease severity classified by mild to moderate bilateral involvement, recovery on the pull test, some postural instability and independence during ADL (Hoehn & Yahr 1967).

Mobility is defined as the ability to move about in an environment, where the outcome is determined by the dynamic interplay between capabilities and the demands of the environment (Yong 2010).

Off state medication usage in individuals with Parkinson's refers to a period where medication is wearing off and motor fluctuations are present (Espay et al. 2012).

On state medication usage in individuals with Parkinson's refers to a period where disease-related motor symptoms are controlled, or most under control, by medication (Espay et al. 2012)..

Perpendicular deficits can be defined as "non-optimal movement occurring in any aspect of the perpendicular areas of the body, such as the limbs" (Hulbert et al. 2014, p. 2).

Postural instability refers to alterations in postural control strategies during standing tasks when responding to perturbations or when performing voluntary movements and leads to impaired balance (Smania et al. 2010; Nagal & Singla 2016).

Proprioception is the ability to sense the position oneself and movement in space (Johnson & Soucacos 2010). See kinaesthetic awareness.

Quality of life is a multidisciplinary concept that reflects the perception of position in life, is influenced by cultural and value systems and specifically relates to standards, expectations, concerns and goals by combining physical, psychological and social aspects with personal experiences and opinions about well-being and satisfaction with health (Zaidman-Zait 2010, Martinez-Martin et al. 2015).

Resting tremor refers to a supination-pronation tremor experienced by PD individuals which typically occurs when their limbs are at rest (Alves et al. 2008).

Rigidity is defined as increased resistance throughout the range of passive movement of a limb (Cole et al. 2010).

Shuffling gait refers to a walking pattern where the feet hardly leave the ground and is often combined with short steps (Eisenberg 1995).

Single-limb support refers to the two periods during a single gait cycle where only one foot is in contact with the ground (Albani et al. 2014).

The **stance phase** occurs while a foot is on the ground, supporting the body weight, from initial contact to lift-off of the supporting extremity, expressed as a percentage of the whole gait cycle (Albani et al. 2014).

Step length is the distance between successive heel contacts of opposite feet and is presented in meters (m) (Salarian et al. 2010).

Step time is the time it takes to complete a left or right step and is presented seconds (s) (Plotnik et al. 2007).

Step width is the lateral distance between the heel centres of two consecutive foot contacts (Bello et al. 2014).

Stride length, synonymous to a single gait cycle, and is defined as the distance between heel-strike and the subsequent heel-strike of the same limb, presented in meters (m) (Salarian et al. 2010).

Stride time is the duration of a single gait cycle and is presented seconds (s) (Salarian et al. 2010).

Stride velocity is the walking speed of an individual, calculated as stride length, in centimetres, divided by stride time, in seconds, and is presented as a percentage of the individual's height (Salarian et al. 2010).

A **stooped posture** is an abnormal forward flexed trunk during normal stance (Bloem et al. 2004).

Sub-Saharan African countries are 'those African countries which are fully or partially located south of the Sahara, excluding the Africa Arabic countries' (Blackenberg et al. 2013, p. 22).

The **swing phase** occurs from toe off to the following foot contact and is expressed as a percentage of the whole gait cycle (Albani et al. 2014).

A **turn** is defined as a change in walking direction (Manciniet al. 2015).

Turn duration refers to the amount of time, in seconds, it takes an individual to make a 180° turn (Salarian et al. 2010).

Turn-to-sit duration refers to the amount of time, in seconds, it takes an individual to perform the transition from a 180° turn to a sitting position (Salarian et al. 2010).

Turn velocity refers to the peak angular velocity when performing a 180° turn (Salarian et al. 2010).

PREFACE

This MSc thesis follows an article-format. The first chapter is a general introduction to the research topic, followed by Chapter 2 with an overview of the literature review on the key concepts of the research. Chapter 2 also concludes with the problem statement including the main research aim with objectives. This is to ensure that the reader firstly understands the special population and their symptoms, and understands the current research on exercise intervention, especially gait-retraining, before the motivation and rationale for the study. Hereafter research article one (Chapter 3) will address the first, fourth and sixth objectives of the study, and article two (Chapter 4) addresses the second, the last part of the third, the fifth and part of the sixth objectives of the study, while the third research article (Chapter 5) addresses the first part of the third objective of this study. As this is an article-format thesis, there is no methodology chapter. Methodology is explained in the three articles, and is condensed to accommodate word limitations in the selected journals. Chapter 3, 4 and 5 were submitted to peer-review journals and follows their specific referencing format in accordance to the specific journal guidelines. For the purpose of this thesis, the articles (Chapters 3-5) are longer in word count, but will be shortened for publication. Finally, the thesis is concluded with an overall discussion and conclusion, as well as study limitations and recommendations for future studies in Chapter 6. The general thesis follows the Harvard Referencing System 2015-2016.

CHAPTER 1

INTRODUCTION

Due to the neurodegenerative nature of Parkinson's disease (PD), these individuals experience age as well as disease-related decrements in mobility. Mobility is defined as the ability to move about in an environment, where the outcome is determined by the dynamic interplay between capabilities and the demands of the environment (Yong 2010). Parkinson's disease-related decrements in mobility occur due to impairment in the dopaminergic pathway of the basal ganglia which cause inadequate stimulation of the cortical motor centres. This in turn leads to less activation of motor neurons and therefore muscle weakness. This mechanism also correlates to impaired balance, falls and disability (Goodwin et al. 2008). Research suggests disruptions in the dopaminergic pathway of the basal ganglia in individuals with PD affect the modulation and integration of the sensory processes to thereby contribute to their impaired mobility (Chaikeeree et al. 2014).

Individuals with PD experience disease as well as age related decrements in balance and gait which constantly exposes them to a high risk of falling. People with gait impairments may have a higher fall risk due to their compensatory slower walking speed, lower stride frequency and smaller stride length, as is often seen in the elderly (Hak et al. 2013). These decrements are also noticeable in PD with their distinctive walking pattern that presents with reduced arm swing and a shuffle gait pattern as well as their altered postural sway pattern (Hackney & Earhart 2009). Moreover, they characteristically present with decreased static balance (presenting as increased postural sway), decreased dynamic balance as well as a forward trunk lean which predisposes them to a high incidence of forward falls – especially from perturbations during daily activities (Bloem et al. 2001). Bloem et al. (2001) highlighted the importance of fall prevention in PD as those who fell more than once in the previous year are likely to fall again within the next three months. Therefore, individuals with PD are at great risk for injury from falls and strategies to reduce this risk seem evident to investigate. Moreover, falls especially occur during walking and while performing activities of daily living (ADL) - an umbrella term for activities and tasks that individuals routinely perform during their everyday life (Fricke 2010; Hill et al. 2015).

As local dynamic stability is frequently and easily disturbed by external perturbations, the compensatory shuffle gait pattern enables PD individuals to keep their centre of mass close to their base of support (Laufer 2005). This compensatory gait pattern, which presents with short, quick steps, is frequently adopted due to disease-related disruption of normal balance control mechanisms. Other PD mobility impairments include impaired spatiotemporal gait parameters,

during FW (Hackney & Earhart 2009), decreased functional capacity (Canning et al. 2006; Herman et al. 2009) and lower limb muscle strength (Canning et al. 2006; Earhart & Falvo 2013), inadequate timing of muscle activation (Snijders et al. 2011) as well as impaired postural control and proprioception contribute to PD mobility impairments. Therefore, the characteristic PD gait pattern is adopted in compensation to these impairments to ensure a relatively stable position for a longer period of time (Laufer 2005).

With disease development, modulatory problems with gait parameters cause freezing of gait (FOG) as well as larger decrements in mobility. Freezing of gait is one of the major causes of falls in PD. It mostly occurs with gait initiation, during turning, when approaching a narrow space and just prior to reaching a destination (Peterson et al. 2012). To minimize the FOG frequency and severity, mobility task training to improve gait parameters should be included in training programs for these individuals.

In recent years, backwards walking (BW) and running has become an attractive exercise alternative for training (Hooper et al. 2004) and rehabilitation purposes such as for knee rehabilitation (Woo et al. 2009, Brink 2010), low back pain in athletes (Dufek et al. 2011), diabetic peripheral neuropathy (Zhang et al. 2014), attention deficit hyperactivity disorder (Viggiano et al. 2015), stroke (Yang et al. 2007; Michaelsen et al. 2014) and cerebral palsy (Kim et al. 2013; El-Basatiny & Abdel-Aziem 2015). As BW is a novel task for many individuals, impairments in BW abilities have shown to be closely related to measures of balance and risk of falling, especially in the elderly (Laufer 2005).

Looking at improving mobility, all the aforementioned parameters which are affected by PD, have been positively addressed with BW in healthy elderly individuals and other neurological conditions such as stroke and cerebral palsy. This include increased spatiotemporal parameters (Yang et al. 2005; Kim et al. 2013), improved functional capacity (Kim et al. 2013; Michaelsen et al. 2014), increased lower limb muscle strength (Woo et al. 2009; Lee et al. 2013) due to more evenly distriobuted muscle activation (Kim et al. 2013; Michaelsen et al. 2014; El-Basatiny & Abdel-Aziem 2015) as well as improved postural control, proprioception and balance (Laufer 2005; El-Basatiny & Abdel-Aziem 2015). With backwards gait training in healthy adults, cardiovascular fitness can be maintained and musculoskeletal improvements may be transferred from backward to forward gait (Childs et al. 2002; Hoogkamer et al. 2014). From this, it became curious whether these mobility benefits might also be induced with BW training in PD. It was hypothesized that gait retraining in both FW and BW will demonstrate improvements, but that more improvements will yield with BW than with FW. The motivation behind this relates to

proprioceptive deficits in PD, neural excitability with exercise, postural instability in PD, the limited impact of pharmacological treatments for PD and the multi-directional nature of daily tasks.

Firstly, due to proprioceptive deficits in PD, they rely more on visual feedback to regulate their sense of self-motion and body position. Considering that visual feedback is removed during BW, it is suggested that PD individuals will need to rely more on proprioceptive feedback. A previous study from our department by Gregory & Welman (2015), has shown that proprioception can indeed be trained in PD when visual information is reduced. Therefore, if BW can improve proprioception, balance and gait will be improved and have a positive impact on overall mobility.

Secondly, Fisher and collegues (2008) as well as Sehm and collegues (2014) suggest that exercise for PD should be intense for neural excitability. When the prefrontal cognitive circuits are activated sufficiently, motor learning can occur. Due to the novelty of BW, additional attention resources are required. It is presumed that during task training which allows motor adaptation, the PD brain compensates for basal ganglia dysfunction by increasing activity in other areas of the brain (Hackney & Earhart 2011). According to Hackney and Earhart (2009), BW is a complex task for PD individuals. Petzinger et al. (2013) highlighted that complex tasks require high levels of attention, especially for PD individuals. With BW, you need to be cognitively aware of your movements and constantly focus on shifting your weight from one foot to the other in the backward direction. This requires high levels of attention and also makes use of dynamic postural control. By using proprioception and dynamic postural control, cognitive resources are engaged. The combination of sensory and cognitive processing during exercise may result in adaptability of mobility.

The third motivation relates to a shift in centre of pressure in PD individuals. Their limits of stability are especially impaired in the backward direction and postural instability is worst during backward perturbations. Protas et al. (2005) reported that backward perturbations lead to backward falls more easily than forward perturbations would lead to forward falls. Schlenstedt and colleagues (2015) highlighted that backward falls occur more easily in PD individuals due to a disease-related posterior shift in centre of pressure. This not only induces a compensatory forward flexed trunk, but, according to Protas and colleagues (2005), also predisposes them to backward falls. It may be possible that with BW training, PD individuals learn to more easily control their centre of pressure and thereby become less sensitive to backward perturbations.

Fourthly, research has shown that pharmacological treatments as well as surgical and non-pharmacological treatments may improve gait, but their effectiveness decreases as the disease progresses (Curtze et al. 2015). Moreover, pharmacological treatments are ineffective to treat postural instability (Horak et al. 2016) and have limited impact on gait and balance over time (Toole et al. 2005). Therefore, a need to explore alternative rehabilitation approaches to improve gait and balance impairments exists. Training in the reverse direction might be an alternative approach to target overall mobility impairments in PD.

Lastly, as locomotion includes complex multi-directional activities, exercise alternatives should stretch beyond mere forward locomotion. Also, people generally make use of a backward step instead of turning around – especially during tight situations or with sudden movements (Protas et al. 2005). This highlights the importance of being able to maintain one's balance during dynamic activities, especially while performing daily tasks that require backward movements. It has been shown that multidirectional gait and step training reduces fall risk in individuals with PD by improving their gait (Protas et al. 2005). Also, improved coordination through these training methods may decrease FOG severity and frequency in individuals with PD (Peterson et al. 2012). To the researchers knowledge, training in the reverse locomotive direction alone, compared to normal forward gait retraining, has however not yet been investigated in individuals with PD.

Hackney and Earhart (2009) were the first to report that forward gait deficits (previously mentioned) in PD are exaggerated during BW. Other studies that investigated BW in PD reported that gait charateristics during BW are worse under DT conditions (Hackney & Earhart 2011), freezers compared to non-freezers have less coordination during complex tasks (such as BW and turning) (Peterson et al. 2012) and that levodopa have a positive impact on BW abilities, as with FW (Bryant et al. 2011). As BW was a novel task for participants in the aforementioned studies, it is curious what the effect of training in the reverse direction might be on their mobility. Performing BW training in PD may induce benefits as highlighted eaerlier in this chapter.

It is suggested that basic neural mechanisms of gait control are similar for BW and FW; however, the different gait directions might rely on additional, specialised neural circuits for FW or BW specifically (Hoogkamer et al. 2014). Keeping this in mind, circuits specific to BW may overlap with circuits that are affected with PD, and possibly lead to improvements beyond what can be gained from automated circuits, such as with FW. These adaptations might be transferred to FW abilities to thereby enable PD individuals to be more economical and stable during mobility tasks (Hoogkamer et al. 2014).

Parkinson's disease-related characteristics may be improved by BW training to thereby prevent these individuals from injury during complex multidirectional ADL and improve quality of life (QoL). Quality of life is a multidisciplinary concept that reflects the perception of position in life, is influenced by cultural and value systems and specifically relates to standards, expectations, concerns and goals by combining physical, psychological and social aspects with personal experiences and opinions about well-being and satisfaction with health (Zaidman-Zait 2010; Martinez-Martin et al. 2015). As individuals with PD are at a great risk of falling and pharmacological treatment strategies have limited impact over time, alternative rehabilitations approaches should be investigated. As PD is a neurological disorder, a rehabilitative strategy that may affect these individuals on a neurological level is of importance (Hedayatpour & Falla 2015). Even though BW training has shown several positive outcomes in a individuals with stroke (Taipei et al. 2005; DePaul et al. 2011; Kim et al. 2014; Michaelsen et al. 2014) and cerebral palsy (Kim et al. 2013; El-Basatiny & Abdel-Aziem 2015), intervention studies on PD individuals performing BW are scarce (Protas et al. 2005; Shen & Mak 2014; Tseng et al. 2015).

Therefore, the aim of this study will be to compare the effect of backward and forward gait retraining on mobility in individuals with mild to moderate PD by assessing changes in dynamic balance during transitional movements, functional capacity as well as perceived balance confidence and QoL. This might enable individuals with PD to complete high quality ADL with more success and with less fear of falling.Mobility improvements that are of more significance with BW than with FW training may indicate the importance of BW in any training program for individuals with PD. Therefore, BW may be considered an alternative rehabilitation tool for individuals with PD.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Parkinson's disease

Parkinson's disease (PD) is a complex and heterogeneous progressive neurodegenerative disease which may place a high burden on individuals with PD, their families and society.

Individuals are diagnosed with PD by a movement disorder neurologist; however, a definite diagnosis requires post-mortem confirmation (Alves et al. 2008). The main clinical criteria for the differential diagnosis of PD are the presence of bradykinesia, which refers to slowness of movement as well as the progressive reduction of speed and amplitude of repetitive movements (Cole et al. 2010). Furthermore, rigidity, resting tremor or postural instability needs to be present; whereas a symmetrical start of symptoms, falls within the first year after diagnosis and a negative response to levodopa should be absent (Nagal & Singla 2016). Postural and gait impairments develop more rapidly than other disease-related symptoms and are therefore the best indication for disease progression (Nagal & Singla 2016). Gait refers to the act and manner of walking or running (Eisenberg 1995), which is one of the most used daily tasks

It is often seen that individuals with PD have restricted abilities to perform activities of daily living (ADL) or that they withdraw themselves from participation in activities due to limitations posed by disease-related motor impairments. Apart from the main motor symptoms, some of the most bothersome functional impairments for individuals with PD include cognitive decline, drooling, swallowing and speech impairments as well as fluctuating responses to medication. The aforementioned impairments may restrict PD individuals from participation in community interactions, resulting in them becoming inactive. Inactivity consequently limits their physical capacity which may further constrain their ADL and increase the risk of developing co-morbidities. Hence, as the disease progresses, individuals with PD experience a reduction in QoL. This is especially true during the later stages of the disease where motor impairments, such as turning difficulty which leads to regular falls; together with non-motor impairments, such as depression and psychosocial problems, are the most important determinants of QoL (Nagal & Singla 2016).

As physical activity may induce a wide spectrum of benefits for PD individuals, it is imperative for clinical exercise therapists to understand the core concepts of the disease, what the influence of exercise may be, as well as the scientific literature to support these findings. For this thesis, the following sections highlight these core concepts i.e. background information on PD; PD

related mobility, which includes backward and forward locomotion; as well as exercise interventions, with the main focus on gait retraining.

2.2 Epidemiology

Parkinson's disease is the second most common neurodegenerative disease following Alzheimer's disease (Alves et al. 2008). Due to methodological and diagnostic differences, there are substantial variations in reported incidence and prevalence rates. The World Health Organization reported an annual PD incidence of 4.5-19 cases per 100 000 individuals (Monteiro-Junior et al. 2015). Worldwide, PD has a prevalence of 16.1 million people (Mazilu et al. 2015; Monteiro-Junior et al. 2015). In 2005, the amount of individuals with PD over the age of 50 years was between 4.1 and 4.6 million. It is estimated that by 2030, this number will be between 8.7 and 9.3 million individuals worldwide (Wirdefeldt et al. 2011). Compared to Europe (up to 539 per 100 000 people), lower PD prevalence is reported in North America (up to 224 per 100 000 people), Asia (up to 32 per 100 000 people) and Africa (up to 20 per 100 000 people) (Wirdefeldt et al. 2011).

Most people with PD are diagnosed with the disease after the age of 60 years. Up to two percent of individuals over the age of 65 suffers from PD, with an increase in disease prevalence of up to 5% in individuals over 85 years of age (Alves et al. 2008). However, some studies report a decline in the prevalence of PD in individuals over 80 years (Wirdefeldt et al. 2011). As individuals who are diagnosed with PD at a younger age have longer duration of the disease and treatment thereof, they experience a higher rate of treatment-related motor complications than individuals diagnosed with PD at an older age (Alves et al. 2008). The PD age of onset may not have a large influence on neuropsychological performance albeit pharmacological treatments might (Schneider et al. 2015). The aforementioned factors, i.e. age of onset and pharmacological management, should both be carefully considered when referring to epidemiological statistics in sub-Saharan African (SSA) countries. In spite of some literature on the epidemiology of PD in SSA countries, published studies on the epidemiology of PD in South Africa itself are scarce.

Sub-Saharan African countries are 'those African countries which are fully or partially located south of the Sahara, excluding the Africa Arabic countries' (Blanckenberg et al. 2013). Prevalence rates in the eastern and western countries of Africa are much lower compared the northern African countries, which may be due to the difference in population structure as well as socioeconomical and cultural factors (Wirdefeldt et al. 2011). In SSA countries, there is a shortage of health workers and resources, medication is unaffordable and international aid is rather focussed on infectious diseases and malnutrition than on neurological disorders (Cilia et

al. 2014). These factors can collectively lower life expectancy to 46.5 years, which substantially lower than the general age of PD diagnosis and may partially contribute to the decreased prevalence in SSA compared to developed countries (Pearce & Wilson 2007; Wirdefeldt et al. 2011). Blanckenberg and colleagues (2013) reported that only 3% of the Tanzanian population reaches 65 years of age, compared to 16% of the United Kingdom population. Moreover, the majority of SSA countries have approximately only three neurologists per ten million people, which further complicates the diagnosis, treatment and management of PD (Blanckenberg et al. 2013). On the contrary, as some sub-Saharan countries, such as Tanzania, mostly consist of rural areas, there are fewer pollutants, pesticides and potential harmful factors that may increase the risk of developing PD (Pearce & Wilson 2007). Apart from varied prevalence rates between countries, the occurrence of PD between sexes should also be considered.

Men generally have a higher incidence rate than women (Wirdefeldt et al. 2011). On the contrary, disease onset before the age of 60 years shows no difference between sexes. Considering all age groups, one woman for every 46 men is diagnosed with PD. Even so, this ratio differs between ethnic groups, i.e. 1.58 in Western populations and 0.95 in Asian populations. Generally women with PD reach HY stage 3 earlier and also experience motor fluctuations, dyskinesia (defined by Allen et al. (2010) as involuntary, fidgety movements of high amplitude) and freezing of gait (FOG) earlier than men (Alves et al. 2008).

Individuals with PD have a 1.8-2.3 increased mortality risk which can partially be ascribed to dementia, even though pneumonia (generally occurring in HY stage 5) is the most common cause of death (Alves et al. 2008).

2.3 Aetiology

The exact cause of PD is unknown; however, many factors have been associated with the risk of developing PD, but no causal relationship has been proven. Traditionally, PD has been considered a non-genetic disorder in around 15% of individuals. Mutations of one of several specific genes are now known to be responsible for PD in 5-10% of individuals with PD (Nagal & Singla 2016). Therefore, it is thought that environmental and genetic factors interact to increase one's risk of developing PD.

Over the past few decades, a variety of occupational, environmental and life-style risk factors for the development of PD has been suggested, but yielded inconsistent and contradictory results. The most consistent results for an increased risk of developing PD, is its strong association with exposure to pesticides (Alves et al. 2008). Furthermore, the association between PD and cigarette

smoking has shown a few different outcomes: motor impairments and limitations may make it difficult to smoke; not starting to smoke as a young adult may be an early sign for PD; nicotine might have a neuro-protective effect against the development of PD (Nagal & Singla 2016).

From a genetic point of view, more than 40 different gene mutations that directly affect the loss of dopaminergic neurons have been found. This may especially be true for individuals diagnosed with PD before the age of 40 years and those with a positive family history (Nagal & Singla 2016). Unfortunately, the exact mechanisms are poorly understood (Alves et al. 2008).

2.4 Pathophysiology

In apparently healthy individuals, basic motor behaviour can either occur due to central pattern generators in the brainstem and spinal cord, or it can be produced by neural circuitries, or loops, that connect the basal ganglia and the supplementary motor area (SMA). These connections become dysfunctional with PD to impair the amplitude and timing of movements (Hausdorff et al. 2003).

In PD, the primary area of brain that is affected is the substantia nigra of the basal ganglia. The basal ganglia play an important role in the regulation and control of automatic and rhythmic movements such as gait (Hausdorff et al. 2003). The basal ganglia can be divided into three sets of subcortical nuclei – the globus pallidus, caudate and the putamen.

The globus pallidus, specifically, plays an important role in receiving information related to executive function, motor planning and cognitive control and sending processed information to the frontal cortex for execution. This function is impaired in individuals with PD during rest and under task conditions, compared to healthy elderly (Müller-Oehring et al. 2014). From a neural point of view, degeneration of the substantia nigra causes increased inhibition in the external part of the globus pallidus and decreased inhibition in the internal part of the globus pallidus. The resulting over excitation of the internal part of the globus pallidus, causes increased inhibition of the thalamus, SMA and primary motor cortex. As these regions affect movement planning and scaling, it could lead to hypokinesia (Peterson & Horak 2016).

The caudate plays an important role in planning and goal directed behaviour. During resting states, PD neurophysiology presents with extended connectivity to the thalamic regions and decreased connectivity to the premotor, motor and somatosensory regions. While performing a task on cognitive control (Stroop test), there is less connectivity to the temporoparietal regions and increased prefrontal connectivity, compared to healthy controls (Müller-Oehring et al. 2014). Along with these findings, Müller-Oehring and collegaeus (2014) reported improved cognitive

function on the Stroop test when PD symptoms were less severe. These findings suggest the shift seen in brain activity between rest and task, is a compensatory process to adequately exhibit executive control.

The putamen in the basal ganglia is important in the regulation of movement, executive function, verbal learning and working memory. Even from a mild disease stage, connectivity to the somatosensory and motor cortical regions is abnormally weak from the posterior putamen and abnormally strong from the anterior putamen (Müller-Oehring et al. 2014). Consequently, the disrupted connectivity seen with PD individuals at rest reflects their difficulty in initiating movements and to easily change motor outputs. Müller-Oehring and collegaeus 2014) suggest that with motor task repetition during the early disease stages, individuals with PD can adapt an accommodating network to process resources more easily.

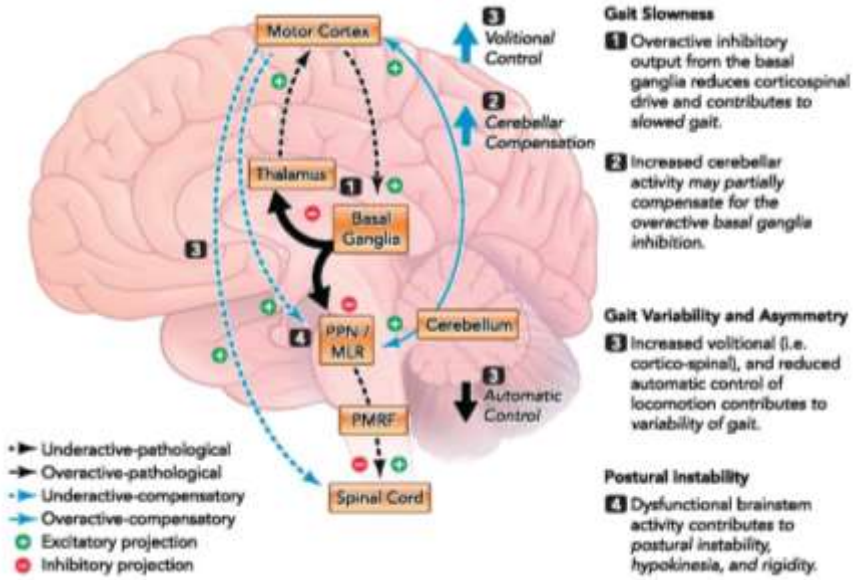
These three subsets interact with the thalamus, cerebellum, frontal cortex and the premotor cortex to form functional circuits as well as cognitive and motor loops with the basal ganglia.

The substantia nigra the basal ganglia contain a specialized set of neurons that send signals in the form of a neurotransmitter called dopamine to the striatum. The neurotransmitter, dopamine, plays an important role in the synchronization and modulation of circuits and loops between and within these brain structures. The activity of this pathway controls normal movements of the body (Nagal & Singla 2016). Accordingly, the main suggested mechanism of PD is the progressive degeneration of dopamine-producing cells in the substantia nigra of the basal ganglia which evidently disrupts connectivity within and between circuits and loops in the brain (Herman et al. 2009; Müller-Oehring et al. 2014).

When neurons in the substantia nigra degenerate, the resulting loss of dopamine causes the nerve cells of the striatum to fire excessively (Nagal & Singla 2016). Literature also suggests that protein mutations form Lewi bodies which contribute to degeneration of dopamine-dependent neurons (Müller-Oehring et al. 2014). Furthermore, disturbances in mitochondrial metabolism increase oxidative stress through reactive oxygen species which contributes to neural degeneration (Müller-Oehring et al. 2014). This degeneration of cells causes less dopamine to be projected from the substantia nigra to the frontal lobes, limbic circuits and striatum. (Hausdorff et al. 2003) report that reduced dopamine availability in the striatum may be responsible for some of the impaired gait parameters seen in individuals with PD.

Parkinson's related impairments of the dopaminergic system in the brain especially occur within extrapyramidal motor circuits. This consequently results in the loss of movement control leading to the primary motor symptoms. *Figure 2.1* illustrates the gait-related disturbances in PD.

a)



b)

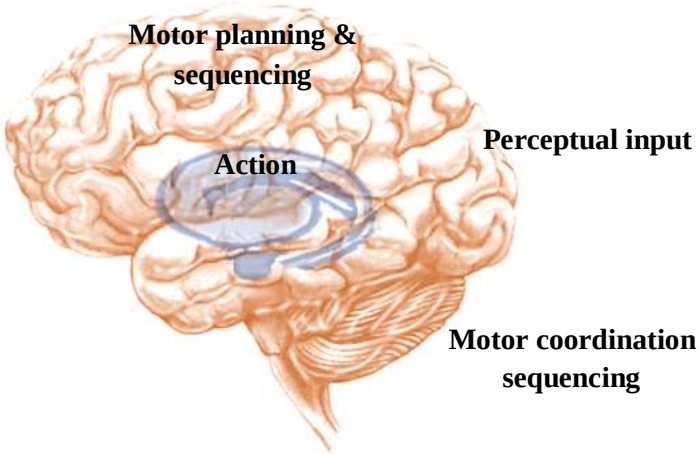


Figure 2.1 *Framework for neural control of locomotion in Parkinson's disease: a) Alterations in activity of the basal ganglia (1) and brain stem (4) contribute to gait slowness and increased postural instability, respectively, and increased cerebral activity may partially compensate for these alterations (2). Increased volitional control (cortico-spinal) and reduced automatic control (3) may contribute to increased gait variability and asymmetry (Peterson & Horak 2016)©. b) Motor performance relies on motor processes including action selection (basal ganglia), sequencing and planning of motor actions (motor cortical regions), and motor coordination and timing (cerebellum) (Moustafa et al. 2016)©. Abbreviations: PPN: pedunculopontine nucleus, MLR: mesencelphalic locomotor region, PMRF: pontomedulary reticular formation, SMA: supplementary motor area.*

2.5 Signs and Symptoms

As individuals with PD present with a wide variety of motor and non-motor signs and symptoms (*Table 2.1*), they experience various activity limitations which might restrict their participation in society and have an influence on their QoL. Moreover, non-motor symptoms such as sleep disorders as well as symptoms from the autonomic nervous, sensory and gastrointestinal systems influences PD QoL (Vandenbossche et al. 2011).

During the early stages of PD, individuals present with rigidity and bradykinesia which relate to the most apparent motor problem namely difficulty with gait. Gait disturbances often present with reduced arm swing and a shuffle gait pattern i.e. short, quick steps (Vandenbossche et al. 2011). Moreover, PD individuals have deficits in maintaining equilibrium during quiet stance as well as during transitions (Nagal & Singla 2016). As the PD signs and symptoms involve a variety of body segments, these individuals have associated difficulty in changing direction or modulating velocity. More specifically, PD individuals have difficulty when transferring from quiet stance to a dynamic state (Bovonsunthonchai et al. 2014). This occurs during many physical activities such as gait initiation, turning and gait termination. Furthermore, PD individuals typically presents with a forward flexed posture, especially during walking.

It is presumed that those PD individuals with dominant bradykinesia and rigidity symptoms demonstrate more deficits in memory, visuo-spatial and executive functions, compared to tremor dominant PD individuals. To investigate the above mentioned functions, a study was done on PD individuals in the off state (aged 59.3±9.2 years of which 23% were women, who had a Unified Parkinson's disease rating scale (UPDRS) motor score of 20.4±6.8 and disease duration of 3.0±2.7 years), to determine the relationship between neuropsychological performance and motor function (Schneider et al. 2015). Seventeen neuropsychological assessments were used to determine their relationship with UPDRS motor subgroups. Tremor appeared to be the most unrelated motor symptom to neuropsychological performance, with no correlation between tremor and any of the tests. The subgroup with posture instability and gait difficulty demonstrated the highest adverse cognitive outcomes, correlating with twelve of the assessments ($r = \geq 0.24$; $p \leq 0.02$). Hereafter, speech and facial expression ($r = \geq 0.22$; $p \leq 0.03$), bradykinesia ($r = \geq 0.22$; $p \leq 0.04$) and rigidity ($r = \geq 0.21$; $p \leq 0.04$) followed, correlating with eight, seven and six assessments, respectively (Schneider et al. 2015).

Apart from differences in the presentation of PD, i.e. age of onset and predominant affected side, PD individuals can also be divided into subtypes based on their dominant features. Thus, PD individuals can be divided into groups where they predominantly experience either tremor

symptoms (TD) or postural instability and gait difficulty (PIGD) (Stebbins et al. 2013). The method of determining these subtypes, have been previously reported (Stebbins et al. 2013; Schneider et al. 2015). A recent study built on the findings by Schneider and collegeaus (2015) by using the Movement Disorder Society's (MDS) UPDRS scale to determine TD and PIGD subtypes. The results found by these authors indicated that the MDS-UPDRS can clearly identify the same subgroups as the UPDRS (Stebbins et al. 2013). Important to note, is that TD individuals responds positively to levodopa, highlighting its association with denervation of dopaminergic structures. Conversely, PIGD symptoms do not respond as effectively to levodopa, suggesting its association with cholinergic systems (Johnson et al. 2016). Even though impaired variables improve in response to medication, between group differences may remain unchanged (Herman et al. 2014b).

2.5.1 Impairments in motor functions and mobility

The four common clinical motor symptoms of PD are bradykinesia, rigidity, resting tremor and postural instability. Also, typically fine motor impairments include mask-like facial expressions and small handwriting (Nagal & Singla 2016). As the disease progresses, postural instability together with gait difficulties become more apparent (Vandenbossche et al. 2011).

a) Bradykinesia

Bradykinesia is defined as the slowness and reduction of voluntary movement such as standing up, walking and sitting down (Cole et al. 2010). This symptom is present in 77-98% of individuals with PD (Albani et al. 2014).

Bradykinesia occurs due to delayed signal transmission from the brain to the muscles and therefore affects the planning, initiation and execution of movements (Nagal & Singla 2016). Bradykinesia most often affects the entire lower limbs (Albani et al. 2014), but can also present as reduced arm swing velocity and lack of axial trunk rotation (Peterson & Horak 2016). Difficulty to initiate walking may lead to FOG or 'freezing' episodes during the more severe stages of the disease (Vandenbossche et al. 2011). Hausdorff et al. (2003) compared motor differences between freezers and non-freezers (i.e. those who do not experience FOG) and found worse bradykinesia symptoms in PD freezers ($p = 0.03$). This illustrates the impact of bradykinesia on mobility that progressively becomes impaired during the later disease stages.

b) Muscle Rigidity

Muscle rigidity, also known as akinesia, is defined as increased resistance throughout the range of passive movement of a limb (Cole et al. 2010). Rigidity is present in 89-99% of individuals with PD (Albani et al. 2014).

Muscle rigidity is caused by increased muscle tone (excessive and continuous contraction of muscles) resulting in muscle stiffness (Nagal & Singla 2016). Individuals with PD experience both axial and limb rigidity (Peterson & Horak 2016). During the early disease stages, rigidity is often asymmetrical and usually presents in the neck and shoulder muscles before the muscles of the face and limbs are affected. Rigidity in the hips, trunk and neck can be 30-50% higher than in healthy matched controls, as highlighted by a recent review (Peterson & Horak 2016). Muscle rigidity often cause muscle pain that is increased with movement, referred to as dystonia (Nagal & Singla 2016).

Axial rigidity, which is rigidity of the neck and trunk, might cause postural deviations such as scoliosis. Trunk rigidity may present with flexion of the pelvis and trunk; possibly preventing important trunk movements that are essential for effective mobilisation (Son & Kim 2015). More specifically, hip rigidity impairs hip extension to directly interfere with step length; and trunk rigidity increases resistance to twisting to thereby induce a slow, en bloc turning style (Peterson & Horak 2016). With disease development, rigidity generally affects the whole body. Therefore, it reduces the ability to move and causes postural deformities that presents with flexion of the neck, trunk, elbows, knees and ankles (Nagal & Singla 2016). Hypertonicity around the hips, knee and ankles pulls these joints into flexion, contributing to spinal abnormalities such as a flexed, or stooped, posture. Due to increased co-contraction of muscles around the joints of the lower limbs, the resulting joint stiffness limits torque. A reduction in torque around the ankle joint is of particular interest as it affects the primary propulsive gait mechanism. Taken together, widespread rigidity contributes to gait slowness (Peterson & Horak 2016). Moreover, asymmetrical rigidity may relate to asymmetrical gait parameters, such as seen with step length variability (Yogev et al. 2007).

Unlike with bradykinesia, Hausdorff et al. (2003) compared motor differences between freezers and non-freezers and did not find differences for rigidity between these two subgroups ($p = 0.58$).

c) Resting Tremor

Tremor at rest is the most well-known cardinal PD motor symptom (Nagal & Singla 2016). Any individual with PD may experience a resting tremor at any stage of the disease. About 30% of individuals with PD do not experience a tremor at the onset of the disease, but most of them develop it as the disease progresses. However, up to 25% of PD individuals never develop tremor (Alves et al. 2008).

Resting tremor refers to a supination-pronation tremor which typically occurs when the limbs are at rest. It is most prominent in the distal part of a limb, usually disappears with voluntary movement and during sleep and is exacerbated by excitement or anxiety (Alves et al. 2008). Tremor is often visible in the hands, fingers, forearms, feet, mouth or chin. It typically appears only in a single limb and over time it becomes bilaterally (Nagal & Singla 2016). It is suggested that tremor results from neural systems that may be distinct from those systems that underlie cognitive function (Schneider et al. 2015).

Still when Hausdorff et al. (2003) compared motor differences between freezers and non-freezers, they did not find significant differences for tremor between these two subgroups ($p = 0.27$). Considering gait characteristics, a recent study noted substantial differences between demographically matched TD and PIGD PD individuals aged 64.6±11.6 years (gender ratio not specified), who had a MDS-UPDRS motor score of 33.4±11.4 in the on state and disease duration of 5.4±3.2 years (Herman et al. 2014b). Individuals of the TD group had faster walking speeds and longer stride lengths under usual ($p < 0.01$) and dual task ($p = 0.01$) conditions, compared to the PIGD group (Herman et al. 2014b).

d) Postural Instability

Postural control refers to achieving, maintaining and restoring a state of balance to maintain posture while moving (Peterson & Horak 2016). Individuals with PD have impaired postural control, relating to postural instability. Postural instability refers to alterations in postural control strategies during standing tasks when responding to perturbations or when performing voluntary movements (Smania et al. 2010). Postural instability leads to impaired balance especially during the later stages of the disease (Nagal & Singla 2016). Up to 65% of individuals with disease duration of five years or more experience postural instability which can highly affect mobility (Nilsson et al. 2012).

Generally, precise segmental control of the head, arms and trunk is required to maintain balance (Peterson & Horak 2016). Poor balance in PD occurs due to the loss of postural reflexes, which

causes unsteadiness and may often lead to falls (Nagal & Singla 2016). Seeing that PD is characterized by abnormal proprioceptive signalling in the basal ganglia, it can be expected that such problems contributes to their postural instability. Individuals with PD's limits of stability are especially impaired in the backward direction and postural instability is worst during backward perturbations (Hackney & Earhart 2009; Peterson & Horak 2016). This may contribute to their postural malalignment in attempt to position the body away from the unstable areas to protect themselves from backward falling (Peterson & Horak 2016).

Balance in the medio-lateral direction is especially impaired in PD, causing increased trunk sway when walking and negotiating obstacles. Moreover, individuals with PD may also have difficulty in achieving balance for gait initiation as well as upper limb movements. The impact of postural instability that relates to impaired balance during voluntary movements reflects the difficulty that PD individuals have with movement control (Peterson & Horak 2016). Consequently, those with PD that predominantly present with postural instability and gait difficulty are grouped into a PD subtype, i.e. PIGD.

Taken together, individuals with PD have difficulty with the coupling of posture and gait, contributing to gait challenges such as reduced step time and FOG (Peterson & Horak 2016). More specifically, PIGD individuals express a correlation with stride-to-stride fluctuations, i.e. stride time variability ($r > 0.47$; $p < 0.01$), that is more than what were found for TD individuals, reflecting as inconsistent stepping and less gait smoothness.

2.5.2 Impairments in non-motor functions and mobility

Even though motor symptoms are the primary characteristics for PD, these individuals can experience non-motor symptoms, such as autonomic dysfunction, sensory-motor difficulty voice disorders and cognitive impairment, at all stages of the disease. Other non-motor symptoms may include hallucinations, olfactory dysfunction, personality changes such as decreased spontaneity and concern for self-care (Vandenbossche et al. 2011). The effect of these impairments on mobility is of interest, especially the effect of impairments in sensory-motor features and cognition.

Sensory-motor symptoms may include prolonged reaction time and pain, especially with more advanced PD, which may restrict mobility and impact QoL. Common features of voice disorders in PD include a reduction in amplitude of sound, problematic sensory perception of effort as well as insufficient internal cueing that causes difficulty in the generation of appropriate effort (Monteiro-Junior et al. 2015). These deficits can also be related to gait impairments where a

shortened stride length is an expression of reduced speech amplitude and where impaired walking rhythmicity reflects deficient internal cueing (Herman et al. 2009).

Cognitive disturbances can be experienced even during the early disease stages and become more prevalent as the disease progresses. Up to 57% of individuals with PD may show evidence of cognitive impairment after 3.5 years of diagnosis (Alves et al. 2008). The most common cognitive impairment in PD is executive dysfunction (Nagal & Singla 2016). Executive function refers to goal-directed behaviour through the use of several cognitive abilities (King et al. 2015). Amongst these are visual-spatial and dual task abilities.

Visual-spatial function significantly correlates with posture, balance and gait impairments ($r = 0.46$; $p < 0.01$) in individuals with PD (aged 59.3±9.2 years of which 23% were women) with disease severity stage of 1 to 3 on the H&Y scale and duration of 3.0±2.7 years. This suggests that there is potential overlapping of neural systems involved in these functions. Therefore, if these neural systems overlap, individuals with PD may benefit on a cognitive level when physical exercise for posture, balance and gait is performed (Schneider et al. 2015). Important to note, participants in the aforementioned study were assessed during the off-state. Hence, the effect of anti-Parkinson medication may play an important role in the generalizability of the results.

Another important aspect of executive functioning is dual tasking abilities. Situations where one performs a secondary task while walking is evident in many activities of daily living such as crossing a street while watching traffic or carrying groceries. Changes in mobility, while dual tasking, are often related to the way in which an individual allocates available attentional resources to each task and for some individuals, maintaining stability under dual task conditions is not a priority (Ullmann & Williams 2011). While dual tasking, individuals with PD generally presents with increased gait asymmetry, compared to normal walking as well as compared to healthy, elderly fallers under the same conditions ($p < 0.01$) (Yogev et al. 2005). This indicates that, apart from clinical symptoms, the regulation of gait may rely on cognitive function and highlights the contribution of executive dysfunction on fall risk during dual tasking which, as mentioned earlier, is evident during many daily activities.

Considering PD subtypes, a study investigated cognitive differences between individuals who predominantly present with TD or PIGD symptoms (Sollinger et al. 2010). Individuals in this study were divided into either the cognitively intact or mild cognitive impairment groups ($p < 0.01$). Apart from cognitive differences, the groups also differed in disease duration ($p < 0.05$).

Sollinger and colleagues (2010) noted that those who presented with mild cognitive impairment had higher PIGD motor scores than the cognitively intact group ($p < 0.05$).

In conclusion, individuals who suffer from motor deficits, cognitive impairment or both might have difficulties regulating gait rhythm and coordinating symmetric leg movements while walking, which become even worse during dual task walking. Given these points, it can be proposed that exercise that requires high levels of concentration might induce more physical and cognitive benefits, than exercise with a low cognitive load.

Table 2.1 Summary of most prevalent Parkinson's disease motor and non-motor symptoms

Motor	Non-motor	
Bradykinesia	Sensory-motor	Prolonged reaction time
Muscle rigidity	Voice disorders	Reduced amplitude of sound
		Impaired sensory perception
		Insufficient internal cueing
Resting Tremor	Cognitive impairment	Executive dysfunction
		Visual-spatial dysfunction
		Impaired dual task abilities
Postural instability	Other	Olfactory dysfunction
		Autonomic dysfunction

2.6 Parkinson's Disease Mobility and Gait

The ability to perform functional activities are crucial for independence and consists of a range of behaviors. Overall functional mobility is associated with a change in body position, where the body's center-of-mass moves outside the base-of-support (Whitney et al. 2005). Functional mobility includes the ability to maintain stable equilibrium during stance, make appropriate anticipatory postural adjustments prior to step initiation, generate speed and temporal coordination of gait, control trunk and arm displacements as well as to produce stable turns while walking (Horak et al. 2016). Physical skills and the related conditions influences functional mobility (Whitney et al. 2005). Therefore, mobility is defined as the ability to move about in an environment, where the outcome is determined by the dynamic interplay between capabilities and the demands of the environment (Yong 2010). The regulation and control of movement is highly affected in PD (Chou & Lee 2013). Mobility difficulties specific to PD includes impaired transitional movements such as gait, postural transitions and turning (Whitney et al. 2005).

The parkinsonian gait mainly impedes mobility in idiopathic PD and is characterized by difficulty in spatiotemporal gait regulation (Nagal & Singla 2016). This difficulty presents with a longer double support time, shortened stride length and a slower walking speed presenting with a compensatory increase in cadence (Canning et al. 2006) as well as increased stride-to-stride variability and a reduction in arm swing (Earhart & Falvo 2013).

Furthermore, Parkinson's gait is characterized by a decrease in angular range together with decreased lower limb flexibility (Peppe et al. 2007; Bello et al. 2014). More specifically, a decreased range for the ankle and hip joints, but not for the knee joint have been reported (Roiz et al. 2010).

From a kinetic point of view, lower limb power production as well as ground reaction forces during heel-strike and push-off are reduced during PD gait and may also be related to muscle weakness and reduced inter-limb coordination (Earhart & Falvo 2013). Therefore, gait asymmetry and altered postural adjustments may occur due to inadequate timing of muscle activity (Snijders et al. 2011).

The aforementioned mobility impairments cause individuals with PD to have a characteristic, disease specific gait pattern (*Figure 2.2*). This gait pattern is referred to as a hypokinetic gait that presents with high frequency, short, shuffling steps (Plotnik et al. 2008; Bovonsunthonchai et al. 2014) with decreased overall speed and a high stride-to-stride variability (Hausdorff et al. 2003). Stride length variability could be an indication of fall risk, marker of FOG and decrease ability to produce steady gait rhythm (Albani et al. 2014).

Individuals with PD may present with FOG as well as frequent, unpredictable falls. Falls and FOG are relatively rare during early disease stages and become more apparent as the disease progresses. They are however closely related. As balance is unexpectedly disturbed when FOG occurs, FOG is a common cause of falls in PD. Even though the pathophysiology of these two symptoms is poorly understood, it is recently suggested that they share common pathologic mechanisms. Both falls and FOG often respond poorly to dopaminergic treatment, suggesting their same underlying pathology (Bloem et al. 2004). These two symptoms pose many negative impacts on well-being, health care costs and society.

Equally important is the abnormal posture that presents with a forward flexed trunk during normal stance, known as a 'stooped' posture (Bello et al. 2014), together with a decrease in lateral bending, torsion and rotation of the trunk during walking (Peppe et al. 2007).

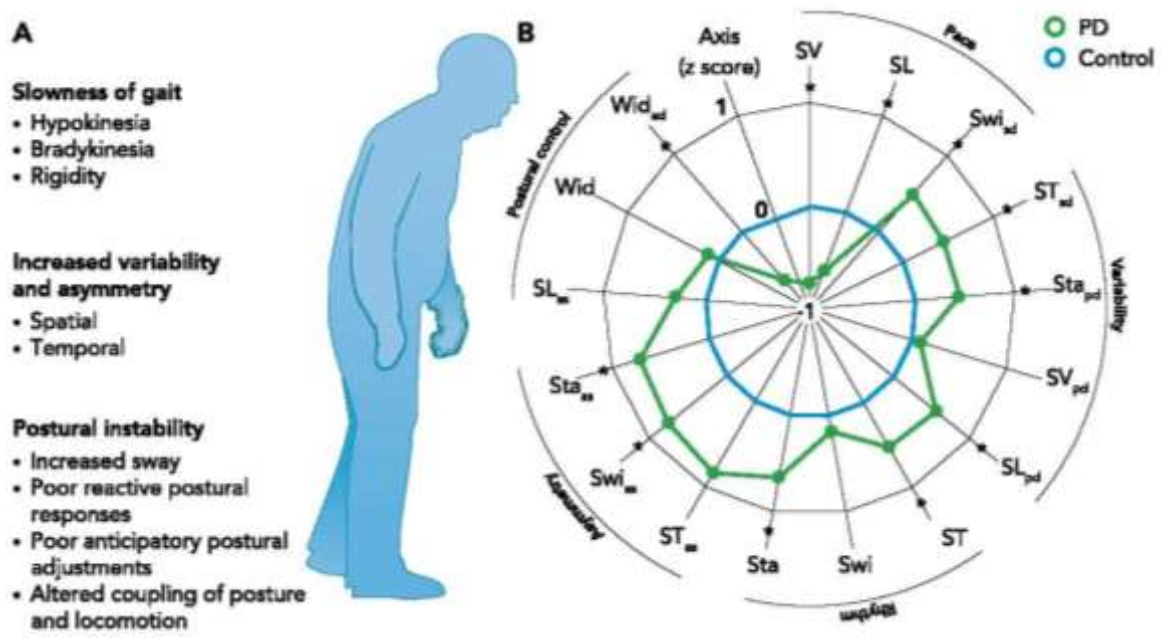


*Figure 2.2: Major gait disturbances in PD (dotted line) compare to healthy, matched controls: a) Continuous gait disturbances in PD. b) PD gait dysfunctional. Abbreviations: SV: step velocity, SL: step length, Swi: swing time, ST: step time, Sta: stance time, Wid: step width, sd: standard deviation (gait variability), as: asymmetry. *Between group differences (Peterson & Horak 2016)©.*

The aforementioned, sometimes unpredictable, transient mobility impairments are common in individuals with PD and worsen from 7% in individuals with early PD to 50% of those with advanced PD (Hausdorff et al. 2003). Furthermore, these deficits also induce difficulty with turning, movement initiation and obstacle negotiation. Therefore, as the disease progresses and these symptoms worsen, treatment efficacy also wanes and gait impairments become increasingly disabling. As gait function worsens, the loss of independence becomes evident together with an increased mortality risk. Therefore, the restoration of walking ability is of primary concern for individuals with PD. Gait speed has shown to be one of the most important symptoms to consider in rehabilitation programs as it is often considered a clinical vital sign of independence, health outcomes and mortality.

2.6.1 Neurophysiological considerations for control of movement

Gait impairments in PD result from the progressive loss of dopamine producing cells in the substantia nigra of the basal ganglia. Initially, alterations occur at the peduncle pontine area,

thereafter it affects the substantia nigra and in the later stages of the disease, the temporal mesocortex and prefrontal cortex are affected (Roiz et al. 2010).

Motor plans are generally set by the premotor cortex and monitored by the basal ganglia to successfully run to completion. The basal ganglia is involved in producing internal cues to provide a movement sequence by stringing together successive elements of a task. Consequently, even though the basal ganglia do not initiate movements, it plays an important role in the monitoring of automatic movement sequences and to mediate action selection (Hausdorff et al. 2003). In other words, individuals with PD have impaired interaction between the basal ganglia and SMA. When this function is impaired, the internal cue production that stems from matching performance outcomes with movement plans is disrupted. Such a disruption results in a diminished gait pattern and gait akinesia (Peppe et al. 2007). Alterations in the execution of motor plans are illustrated in *Figure 2.3*.

Compared to matched healthy individuals, a MRI study on individuals with mild PD, mean H&Y stage of 1.5 (range 1.0 – 2.5), aged 63±6 (55& women) with a disease duration of 3 years (range 0.2 – 8.2 years) has shown decreased activity between the basal ganglia and the SMA as well as the premotor, motor and sensorimotor regions in the PD group, even though the two groups showed comparative cognitive function (Müller-Oehring et al. 2014). Decreased supplementary motor cortex activity is associated with increased cadence, decreased stride length and impaired regulation of step amplitude, as seen in individuals with PD (Snijders et al. 2011). As the disease progresses to more advanced stages, connectivity from the striatum to the thalamus, midbrain and cerebellum becomes impaired. This finding suggests that, even from an early disease stage, communication between the cortical and somatosensory regions becomes partitioned and results in impaired sensorimotor integration (Müller-Oehring et al. 2014). Therefore, brain circuits between cortical and basal ganglia regions are very important for motor behaviour and cognition, especially the combination thereof, in individuals with PD. It is consequently suggested that cognitive performance in PD is significantly influenced by motor demands, which is not seen in the healthy elderly population, and also decreases as the disease progresses (Snijders et al. 2011). Conversely, Sollinger and colleagues (2010) reported that PD individuals, who predominantly present with PIGD, may present with mild cognitive impairment above those who are TD. This indicates that with worse disease symptoms, or with PIGD, fewer resources are available for the basal ganglia to process cognitive information (Alves et al. 2008). As adequate levels of cognitive control highly affect independence, the importance thereof in individuals with PD is clear. Posture, balance and gait may be associated with the highest adverse cognitive outcomes

such as accelerated cognitive decline and an increased risk to develop dementia (Schneider et al. 2015).

The abovementioned impairments may however be compensated for in individuals with PD by the thalamus (Snijders et al. 2011). Therefore, disrupted communication in certain areas of the brain can induce heightened activity in other areas of the brain. This compensation is seen when individuals with PD show abnormal increase in premotor cortical and cerebellar activity while performing a motor task (Müller-Oehring et al. 2014). The thalamus can be seen as a centre of network integration as it is well positioned in the brain and has ample circuits and loops to be able to reconcile functional networking between subcortical and cortical regions in order to compensate for PD related neural compromise (Snijders et al. 2011). The relationship between thalamus connectivity and levodopa usage possibly suggest dynamic synchronization within thalamic loops through dopaminergic mediation (Müller-Oehring et al. 2014). This is an important finding for individuals with progressed PD, as the use of levodopa may cause greater thalamic activation to thereby induce compensatory neural adaptations and attribute to improved walking parameters, such as step amplitude and gait rhythm (Toole et al. 2005).

This finding is also supported by Snijders et al. (2011) who found altered brain activity that was not explained by altered motor execution, somatosensory processing, task performance or brain atrophy. This altered brain activity was demonstrated in healthy controls and PD individuals without FOG who recruited their SMA, but was not seen in PD individuals with FOG. Those with FOG rather showed increased activity in the mesencephalic locomotor area and the anterior cingulate cortex, than in the superior parietal lobe. Even though the mesencephalic locomotor area is used during motor imaging of gait in healthy individuals, it is inhibited by the basal ganglia to not produce actual motor actions. As altered activity in this area is seen in those who freeze, it is suggested to be a pathological decrease in basal ganglia inhibition (Snijders et al. 2011). The mesencephalic locomotor area also plays a compensatory role to support gait planning and execution. As this region's ability to control gait is limited, increasing gait demands may cause this compensatory system to collapse and evoke FOG. Apart from FOG, failure of additional gait-related cerebral structures induces difficulties with turning, gait initiation or obstacle negotiation (Hausdorff et al. 2003; Snijders et al. 2011).

Toole et al. (2005) suggests two neural pathways that may contribute to obstacle-related walking performance. Firstly, neural circuits between the basal ganglia and SMA regulate the basic movement pattern. Secondly, a separate pathway that is not dopamine dependent mediates the effects of visual inputs on walking. Therefore, visual input may modify a basic locomotor pattern

through a secondary neural system that is located outside the basal ganglia. These two pathways regulate walking performance according to specific visual constraints. In individuals who freeze, both these systems may be impaired (Toole et al. 2005). In agreement with this, Albani and collegues (2014) reported that part of the gait mechanism is under the control of non-dopaminergic structures. For instance, distal limb movement control can be performed by the cortico-subcortical areas. Likewise, pelvic motion is under the control of reticolospinal pathways for stability. Both these examples affect mobility in those with PD. Consequently, it seems that PD mobility impairments may not only stem from dopaminergic structures in the brain, especially during the later stages of the disease (Albani et al. 2014).

The aforementioned alterations in neural connectivity induce the distinctive PD hypokinetic walking pattern which (as stated before) typically presents with increased stance phase time as well as decreased foot clearance caused by reduced walking velocity and shorter stride lengths, resulting in the PD specific shuffle gait pattern (Peppe et al. 2007).

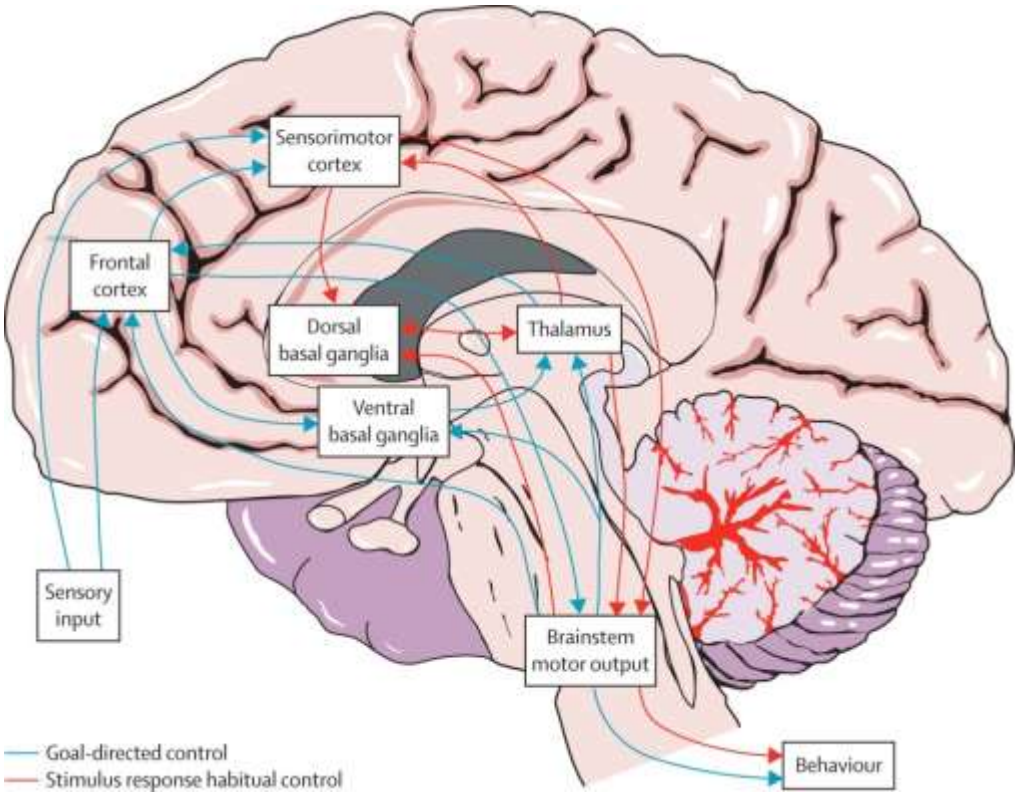


Figure 2.3. *Cognitive and automatic control of movement control in Parkinson's disease. The blue arrows represent cognitive, or volitional, circuits. The red arrows represent the automatic circuits. In Parkinson's the loss of dopamine inhibits automatic motor control (red arrows), which leads to over-reliance on cognitive circuits (blue arrows)* (Petzinger et al. 2013)©.

2.6.2 Spatiotemporal parameters of PD gait

Spatiotemporal parameters include the different variables of walking, i.e. gait cycle phases, stride length, cadence and velocity. From a clinical point of view, the asymmetry and variability of these variables are of importance.

Neural regulation, particularly of the leg extensor muscles, is impaired in individuals in PD and is therefore extensively controlled by reflex mechanisms such as Golgi tendon organs. This shift in control causes decreased force production which presents with reduced stride height, SL and walking speed (Toole et al. 2005). The consequence of impaired control of force production while walking results in a shuffle gait pattern. Moreover, uncoordinated antagonist muscle groups, especially in the lower limbs, may relate to a defective walking pattern. Speed of walking is highly determined by the power phase, or push-off phase, of the gait pattern. During FW, activity of lower leg extensor muscles is important to generate a long and brisk stride (Toole et al. 2005). Consequentely, impaired neural regulation induces changes in spatiotemporal parameters of PD gait.

The comparison of spatiotemporal parameters of in individuals with PD compared to healthy age-matched individuals has been extensively researched (Peppe et al. 2007; Roiz et al. 2010; Albani et al. 2014; Bello et al. 2014). The following subsections elaborate on spatiotemporal parameters of individuals with PD.

a) Gait cycle phases

The gait cycle (GC) can be divided into two phases – a stance and a swing phase. A stance phase occurs while a foot is on the ground, supporting the body weight, from initial contact to toe-off of the supporting extremity. Hereafter, the same foot enters the swing phase, which occurs from toe off to the following foot contact (Albani et al. 2014).

Some studies found the GC time to be increased, compared to healthy individuals (Peppe et al. 2007; Roiz et al. 2010; Albani et al. 2014). It appears that average stride time only has secondary importance to gait disturbances in PD as it is not related to any measures of disease severity or duration and is not responsive to levodopa (Schaafsma et al. 2003).

Peppe et al. (2007) performed a study on individuals with PD (aged 6.5±9.8 years of which 63% were women) and matched healthy controls. The PD group had a disease severity of 2.3±5 on the H&Y scale and disease duration of 6.7±4.2 years and all of them were hospitalised. Results showed the stance phase of individuals with PD to be 68.1% of the GC compared 63.6% of

healthy controls, which can be attributed to a decrease in walking speed as well as bradykinesia ($p < 0.01$). A more recent study elaborates on stance phase duration in PD (Albani et al. 2014). An increase was found for stance phase duration between individuals with PD individuals aged 6.9±9.7years (of which 46% were women) who had a disease duration of 5.9±4.6 years, who were divided into early or more severe PD (H&Y score <2 and ≥2 respectively), and matched healthy controls ($p < 0.05$). It is however important to note that participants used by Albani et al. (2014) were tested in the off-state.

Peppe et al. (2007) also reported a similar trend with double limb support equalling 17.9% of the GC in the PD group compared to 14.1% in the control group ($p < 0.01$). More time spent in the double support phase may reflect PD individuals' inability to successfully transfer their weight in preparation for stepping to adequately shift their centre of mass forward. This may occur in compensation to their postural instability (Peppe et al. 2007).

b) Stride length

Stride length (SL), synonymous to a single GC, is defined as the distance between heel-strike and the subsequent heel-strike of the same limb, presented in meters (m) (Salarian et al. 2010).

A decrease in SL were found between individuals with PD aged 63.7±8.3 years (of which 42% were women) who had a disease severity of 2.8±0.5 on the H&Y scale and disease duration of 6.6±4.3 years, and matched healthy controls when they walked in their preference pattern ($p < 0.01$) (Roiz et al. 2010). This finding is also supported by (Snijders et al. 2011) who included PD individuals with FOG (aged 58.7±9.0 years; 34% women) who had a UPDRS III score of 34.6±9.6 and disease duration of 9.8±4.6 years, and matched non-freezers (both groups in the off-state) and controls as well as by Peppe et al. (2007).

Canning et al. (2006) (Canning et al. 2006)confirmed SL decrements in PD (aged 65.0±6.9 years; 19% women) who had a H&Y score of 2.4±0.5 and disease duration of 7.2±5.0 years, compared to matched healthy participants, over longer distance walking in a six-minute walk test (6MWT; $p = 0.01$). Conversely, average stride time may be more related to cadence, and the control of cadence, that is generally intact in individuals with PD (aged 62±7.5 years; 28% women) who had a H&Y score of 2.9±0.6 and disease duration of 9.6±3.9 years (Schaafsma et al. 2003). The aforementioned findings are also reported by Almeida and Lebold (2010).

c) Cadence

Cadence, or step rate, is the number of steps per minute (steps/min) (Salarian et al. 2010). As indicated in the above section, the control of cadence is usually intact in individuals with PD (aged 72.4±6.8 years; 35% women) who had a UPDRS total score of 32.8±7.34 and disease duration of 9.1±5.3 years (Almeida & Lebold 2010), but some individuals may increase their step rate to compensate for their reduced SL (Schaafsma et al. 2003). This especially occurs in individuals with early PD without FOG that may show a higher cadence than those with a higher disease severity and FOG ($p < 0.05$) as was recently reported by Albani and collegues (2014).

Canning and colleagues (2006) compared spatiotemporal parameters over short and long distances between PD individuals and healthy controls and found no differences in cadence during a 6MWT ($p = 0.84$). Conversely, Peppe and colleagues (2007) reported a lower cadence between individuals with PD and healthy controls when they walked in their preference pattern ($p < 0.01$).

d) Velocity

Stride velocity (SV) is the walking speed of an individual, calculated as SL (in centimetres) divided by stride time (in seconds) and is presented as a percentage of the individual's height (Salarian et al. 2010).

It has been reported that SV is reduced ($p < 0.01$) in individuals with PD compared to controls when walking at a preferred pace (Roiz et al. 2010). Reduced walking speed (as indicated by SV) is considered a reliable and valid measure of mobility for PD individuals of all severity stages (Hass et al. 2014).

Canning and colleagues (2006) found results on comfortable walking speed over a short distance (8m) compared to velocity maintained during a 6MWT. Individuals with PD walked slower than the healthy control group over the 8m test at comfortable walking speed ($p < 0.01$) as well as during the 6MWT ($p = 0.01$). However, during the fast-as-possible trial on the 8m walk test, both groups walked at comparable velocities ($p = 0.70$). During the 6MWT, the PD group walked at a lower percentage of their fast-as-possible velocity over 8m (76%±5%) compared to the control group (84%±75%; $p < 0.01$).

The decrease in SL and SV found in individuals with PD is often associated with one another. The decrease in gait velocity may be related to SL shortening without a decrease in cadence. A decrease in cadence in individuals with PD may also contribute to a reduced velocity. Individuals

with H&Y stages 1 and 2 (unilateral to bilateral disease without balance impairment) often show a decrease in gait velocity, but with no significant differences in SL, compared to healthy controls (Hoehn & Yahr 1967; Roiz et al. 2010). Therefore, the decrease in velocity for PD individuals in the early disease stages may be related to a decreased cadence. However, participants classified as H&Y stages 2.5 – 3 do often not present with a significant decrease in cadence, compared to controls (Roiz et al. 2010). In other words, for PD individuals with the aforementioned severity classification, the reduction in velocity may not be related to cadence, but rather to a shortened SL. This finding contradicts findings by Albani and collegues (2014) that tested participants in the off-state. It is therefore noteworthy that cadence may be restored when individuals with early PD are in the medicated state.

Even though individuals with PD are capable of reaching higher walking speeds, the results from Canning et al. (2006) suggest that they walk at a default velocity which can be maintained automatically without too much attentional resources. This makes velocity of walking the largest contributor to functional capacity (FC).

Gait velocity can decrease from 1.11m/s in PD individuals with H&Y stage 1 to 0.82m/s for those with H&Y stage 3 (Hass et al. 2014). Physical therapy, compared to no intervention, has however shown to improve gait speed by a mean difference of 0.05m/s (Hass et al. 2014). Therefore, walking speed should be one of the primary spatiotemporal considerations during rehabilitative programs to delay the progressive decrease in gait velocity.

e) Gait asymmetry

Gait asymmetry in the lower extremities is defined as the bilateral coordination of the timing of swing durations during gait, i.e. the swing times of one leg compared to the swing time of the contra-lateral leg (Yogev et al. 2007).

Snijders et al. (2011) reported that individuals with PD generally presents with increased gait asymmetry compared to healthy controls ($p < 0.01$). Moreover, gait asymmetry in PD individuals without FOG (aged 64.8±7.4 years; 44% women) who had a H&Y score of 2.7±0.4 and disease duration of 10.0±4.0 years) does not correlate with asymmetric motor symptoms as derived from the UPDRS III ($\rho = 0.02$; $p = 0.93$). Moreover, gait asymmetry was higher in matched PD individuals with FOG ($p = 0.02$) (Plotnik et al. 2005).

Yogev et al. (2007) investigated gait asymmetry in PD individuals (aged 71.9±7.3 years; 19% women), healthy elderly (aged 67.5±3.5 years; 45% women) and elderly fallers (aged 76.3±4.9 years; 53% women) under usual walking and dual task walking conditions. A noteworthy

decreased cognitive function was found in both the PD individuals ($p < 0.01$) and fallers ($p < 0.02$). During normal walking, gait asymmetry has shown to be impaired in the PD individuals and fallers ($p = 0.01$). Gait asymmetry became even more impaired when the PD individuals ($p < 0.01$) and fallers ($p < 0.01$) performed dual task walking. As only 31% of gait asymmetry during normal walking and 15% during dual task walking could be attributed to discrepancies in SL, the authors noted that gait asymmetry in PD is not related to SL discrepancies. The authors of this study concluded that gait asymmetry may be a relative independent measure of gait disturbances that reflects a distinct pathological process. More specifically, they suggest that the differences in left-right swing times may be highly dependent on cognitive function (Yogev et al. 2007). Moreover, Peterson and Horak (2016) noted that gait asymmetry may be related to asymmetric bradykinetic symptoms and rigidity in both the upper and lower limbs.

f) Gait variability

Individuals with PD experience gait disturbances such as gait instability and arrhythmicity. Gait arrhythmicity presents with stride-to-stride variability during walking (Yogev et al. 2007) and reflects the neural control of rhythmical stepping under unconscious control (Lord et al. 2011). Gait variability refers to the variability seen in spatiotemporal gait parameters between steps and is presented as the coefficient of variation of a specific parameter (Albani et al. 2014). Gait variability can also be indicated with the gait variability index (Balasubramanian et al. 2015) or by calculating within-subject standard deviation (Hausdorff et al. 2003).

Albani and colleagues (2014) reported difference in variability of cadence, SL and stride time of PD individuals in the off-state compared to healthy participants ($p < 0.05$). During the on-state, stride time variability has been reported to be related to UPDRS total score ($\rho = 0.46$; $p = 0.01$), UPDRS part II ($\rho = 0.45$; $p = 0.01$), UPDRS part III ($\rho = 0.54$; $p < 0.01$), rigidity ($\rho = 0.36$; $p = 0.04$), and bradykinesia ($\rho = 0.47$; $p = 0.01$) but not to tremor ($\rho = 0.06$; $p = 0.75$) (Schaafsma et al. 2003).

It is presumed that medio-lateral (step width) variability is related to the maintenance of balance during gait while step-to-step width is actively adjusted. Step width variability may therefore reflect difficulty in the control of lateral postural equilibrium. In contrast, anterior-posterior variability appears to be unrelated to step-to-step balance adjustments, but rather related to fluctuations in gait speed (Peterson & Horak 2016).

With regards to anterior-posterior variability in PD, Peterson and Horak (2016) noted that variability between steps increases before a reduction in step length is observed while only step

length, not step variability, is improved by levodopa. In contrast, Hausdorff et al. (2003) reported improvement of gait variability in response to levodopa and suggested that gait variability stems from an impaired central, dopamine-dependent mechanism.

Furthermore, literature suggests that an irregular gait rhythm stems from an inability to generate muscle force at a constant level. This inability indicates an exaggerated impairment of the internal pacing function in PD individuals (Schaafsma et al. 2003). Hausdorff et al. (2003) suggest that gait variability may occur as a primary function of impaired control of gait rhythmicity and stability which may over time worsen and lead to FOG in situations where control is severely affected.

This is reported by Hausdorff et al. (2003) who highlighted that stride-to-stride variability increases with disease severity, as shown when PD individuals with FOG (aged 64.1±7.4 years; 36% women) with disease duration of 11.1±5.0 years and UPDRS III score of 14.5±5.9, is compared to matched individuals without FOG (UPDRS III score: 8.7±5.5; $p = 0.02$) (Hausdorff et al. 2003).

As stride time variability is not only related to falls and motor performance, but also to ADL, it plays an important role in the mobility of individuals with PD ($p < 0.01$). Henceforth, stride time variability may reflect the inability of individuals with PD to generate and perform automatic, self-paced sequential and rhythmic movements (Hausdorff et al. 2003; Schaafsma et al. 2003). Therefore, gait variability increases with disease progression up to a certain point, and then causes a freezing episode in the more severe disease stages. This finding explains how gait variability is a risk factor for possibly developing FOG, which is a transient albeit continuous abnormality.

Findings by (Yogev et al. 2007) demonstrate the correlation between swing time variability a gait asymmetry during usual walking ($\rho = 0.35$; $p = 0.02$) as well as during dual task walking ($\rho = 0.42$; $p < 0.01$). This illustrates the influence of cognitive loading on gait variability and automaticity, which may exacerbate PD individuals' risk of falling.

As elaborated above, gait variability is related to disease severity, fall risk and frequency of freezing episodes (Hausdorff et al. 2003; Schaafsma et al. 2003; Yogev et al. 2007). Hence, interventions that improve gait variability might improve these variables as well (Plotnik et al. 2005).

2.6.3 Postural control and balance

Postural control refers to achieving, maintaining and restoring a state of balance to maintain posture while moving (Peterson & Horak 2016). Postural instability refers to alterations in postural control strategies during standing tasks when responding to perturbations or when performing voluntary movements and leads to impaired balance (Smania et al. 2010; Nagal & Singla 2016). Postural instability is one of the hallmark symptoms of PD and is a major contributor to fall risk, fear of falling, inactivity and reduced QoL (Allen et al. 2010). Derived from PD-related postural instability are adaptations in other postural systems such as abnormal postural responses, compensatory arm movements and ineffective sensory integration (Earhart & Falvo 2013).

Poor balance in PD occurs due to the loss of postural reflexes, which causes unsteadiness and may often lead to falls (Nagal & Singla 2016). In order to prevent an actual loss of balance, increases in medio-lateral and backward margins of stability compensates for a potential decrease in local dynamic stability in healthy elderly individuals. More specifically, medio-lateral margins of stability can be increased by increasing stride frequency, while backward margins of stability can be improved by either increasing walking speed or by decreasing stride length. When walking speed is limited, walking with fast and short steps at a certain speed, results in the largest medio-lateral and backward margins of stability (Hak et al. 2013). These compensatory gait adaptations due to poor balance and impaired proprioception are presented in PD as a shuffling gait pattern, as brought to light by Hackney and Earhart (2009).

Seeing that PD is characterized by abnormal proprioceptive signalling in the basal ganglia, it can be expected that such problems contributes to their postural instability. Proprioception is the ability to sense the position oneself and movement in space (Johnson & Soucacos 2010). Individuals with PD's limits of stability are especially impaired in the backward direction and postural instability is worst during backward perturbations (Hackney & Earhart 2009; Peterson & Horak 2016).

The impact of postural instability that relates to impaired balance during voluntary movements reflects the difficulty that PD individuals have with movement control (Peterson & Horak 2016). Postural instability has also shown to be resistant to dopamine-replacement therapy (Toole et al. 2005). Investigative research on other neurotransmitters and areas beyond the basal ganglia, has shown that decreased functioning of norepinephrine in the *locus coerleus*, which is normally not affected by normal aging, might influence balance, automatic responses, cognition and motor

control (Earhart & Falvo 2013). Consequentely, individuals with PD have difficulty with the coupling of posture and gait, contributing to mobility challenges (Peterson & Horak 2016).

Due to the novelty of BW, it is generally less automated than FW. The visual-spatial processing and sensorimotor control required for BW activates higher levels of the cortical areas. Considering that postural instability is a hallmark of PD has also shown to be resistant to dopamine-replacement therapy (Toole et al. 2005), increasing activity in the motor cortex, i.e. with BW training, may enhance the control of stability.

2.6.4 Freezing of gait

Freezing of gait (FOG) is the sudden, episodically inability to generate effective forward stepping in individuals with PD, where normal, voluntary movement is interrupted (Snijders et al. 2010). Freezing of gait is an extreme form of bradykinesia and is described as a feeling of being glued to the floor (Hausdorff et al. 2003). Freezing of gait is often experienced during usual walking, presenting as the inability to continue moving forward; when movement is initiated, referred to as a start hesitation; during turning; when negotiating narrow spaces or obstacles as well as when reaching a target (Hausdorff et al. 2003; Bovonsunthonchai et al. 2014), lasting from a few seconds, up to two minutes (Mazilu et al. 2016). FOG during these activities is particularly evident in crowded places and during time-restricted, stressful situations. As PD freezers cannot be prepared for a freezing event, they experience a loss of control over their own body with regards to mobility. Considering the social consequences that this might have, FOG has a direct effect on QoL (Moore et al. 2007). *Figure 2.4* illustrates the clinical impact of FOG in PD.

Freezing becomes a symptom during the later disease stages in between 20% and 70% of PD individuals, especially those with prolonged levodopa treatment (Hackney & Earhart 2011; Mazilu et al. 2016). Up to 26% of individuals who are in the early stages of PD who do not use levodopa, may experience FOG. Furthermore, up to 80% of PD individuals may not experience FOG at any stage of the disease. It is thus clear that even though FOG is associated with disease progression and duration of levodopa treatment, it may be an independent feature in individuals with PD (Bloem et al. 2004). This finding suggests that FOG may occur due to a specific pathological mechanism that is not present in all individuals with PD. Moreover, Beck and colleagues (2015) recently highlighted that a universal mechanism that explains the occurrence of FOG, has not yet been established.

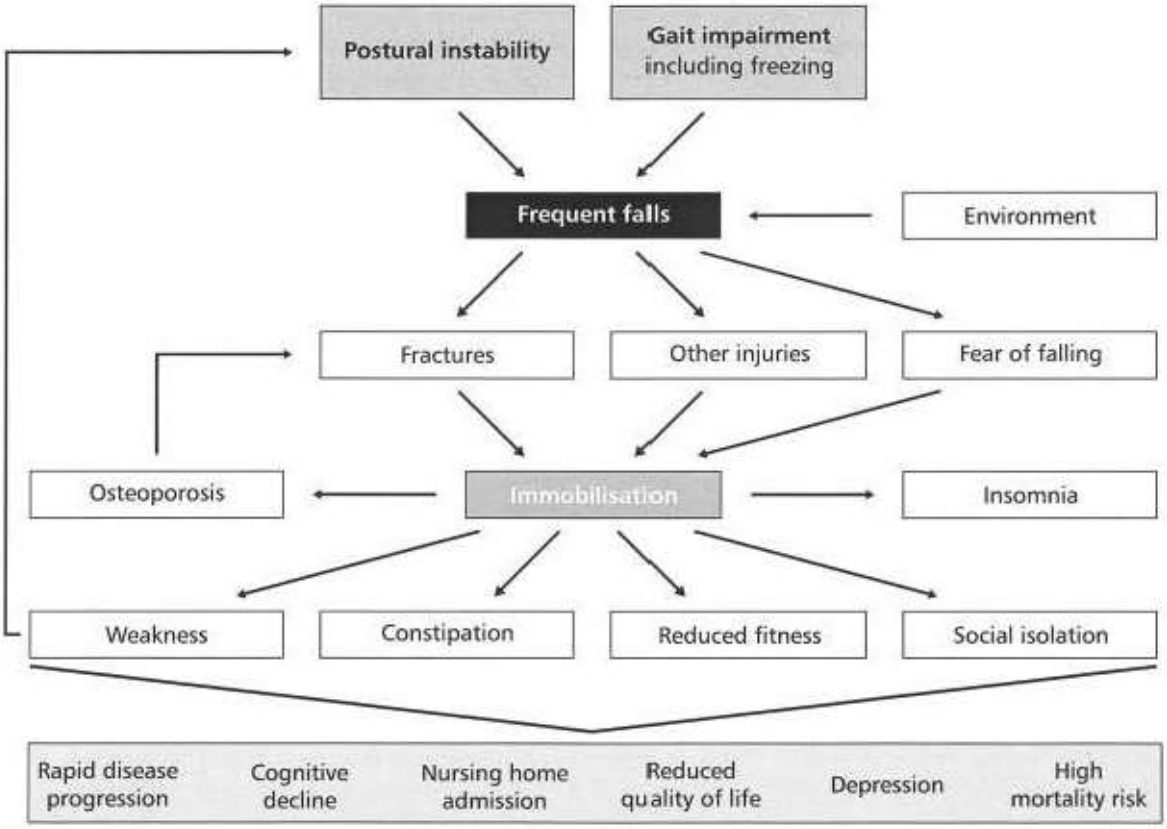


Figure 2.4 *Diagram shows clinical impact of freezing of gait and falls in Parkinson's disease (Bloem et al. 2004)©.*

There are three different subtypes of FOG that may present in individuals with PD. The most common type of FOG presents as in-place trembling of the legs which is frequently associated with an effort to overcome the block that is associated with FOG. The second and best known type is known as akinesia where individuals with PD are unable to start walking or fail to continue to move forward, for no apparent reason (Bloem et al. 2004; Mazilu et al. 2016). The third type of FOG is also known as festinating gait, which is characterized by involuntary accelerated, small steps during locomotion, with the body leaning forward, as if chasing its centre of gravity (Eisenberg 1995).

The first type of FOG, trembling, is very distinct from the classic tremor that individuals with PD experience. Trembling during FOG differs in frequency from classic and gait related tremor. Research suggests that trembling during FOG may be independently generated or may occur due to misfired oscillators which force the legs to move too fast for effective stepping. The possible reasons for trembling during FOG are not yet known – it can be activated involuntary or occur in effort of overcoming the freezing motor block (Bloem et al. 2004).

The second type of FOG, namely akinetic episodes, often presents itself as start or turning hesitations during the early disease stages. Unilateral freezing occasionally occurs in individuals

with asymmetrical PD. These FOG episodes mostly last less than 10 seconds, but a few might last more than 30 seconds. As these FOG episodes are generally short in duration, they cause relatively mild functional impairments and rarely lead to falls (Bloem et al. 2004).

The third type of freezing, gait festination, refers to the characteristic visible, walking pattern in individuals with PD, presenting with a shuffling gait which is also known as a hypokinetic gait pattern (Bello et al. 2014; Mazilu et al. 2016). Shuffling, or hypokinesia, is produced when the feet barely leave the ground and results in short, quick steps (Eisenberg 1995; Bello et al. 2014). To compensate for impaired stability and limited walking speed, walking with fast and short steps at a certain speed, results in the largest medio-lateral and backward margins of stability for individuals with PD (Hak et al. 2013). Hausdorff et al. (2003) suggests that the characteristic hypokinetic PD gait may be related to disturbances within a specific motor plan, either with the motor set for whole movement sequences or with the stringing together of sub-movements within this motor plan. Either way, over time, it exposes these individuals to developing other types of FOG and a high fall risk.

As the disease progresses, FOG becomes much more disabling and occurs more frequently, especially in the off-state of medication usage (Albani et al. 2014). The off-state refers to medication withdrawal where motor fluctuations are present; whereas the on state in individuals with PD refers to the peak effect of usual medication where disease-related motor symptoms are controlled, or most under control (Espay et al. 2012). Espay et al. (2012) elaborated on the dilemma of FOG which alleviates during lower dosages dopaminergic treatment, but in doing so, other disease-related features are exacerbated. Despite the lack of definite mechanisms to explain the aforementioned findings, a few models have been proposed, i.e. cognitive and sensory-perceptual viewpoints (Beck et al. 2015).

Cognitive models become evident during dual tasking, which may evoke FOG. In such circumstances, attention is divided and directed away from walking. As walking is less automatically controlled in PD, the imposed motor disruption may result in freezing. However, when external cueing is used, attention is focused on each step. Therefore, the gait pattern is changed from automatic to attention-driven stepping, which may alleviate the incidence of FOG episodes (Beck et al. 2015). In contrast to this, FOG episodes are also evident in conditions with a low cognitive load, such as approaching a doorway or obstacle. Beck and colleagues (2015) proposed a faulty sensory-perceptual model is during such conditions.

Individuals with PD (aged 72.0±7.2 years; 11% women) who had a UPDRS III score of 38.8±10.6 (disease duration not reported) and who experience FOG, demonstrate associated balance and lower limb impairments and present with different gait patterns than matched PD individuals (24.7±7.5) who do not freeze (Beck et al. 2015). More specifically, decreased step length ($p < 0.01$) and velocity ($p < 0.01$) as well as increased variability in step length ($p = 0.02$), step time ($p = 0.01$) and double support percentage ($p < 0.01$) were highlighted to be predicting gait parameters of FOG; whereas gait asymmetry ($p = 0.50$), step time ($p = 0.08$) and percentage double support time ($p = 0.33$) do not differ between these subgroups (Beck et al. 2015). Other researchers support these findings in impaired gait parameters and kinetic variables of freezers, compared to non-freezers (Hausdorff et al. 2003; Snijders et al. 2011; Albani et al. 2014; Bovonsunthonchai et al. 2014).

The change in gait characteristics just prior to a freezing episode is suggested to be due to a combination of an increasing inability to generate SL that is superimposed on impaired control of cadence (Hausdorff et al. 2003). Participant characteristics from Hausdorff et al. (2003) are previously reported. These authors showed increased gait variability just prior to and after a freezing episode, which differed from gait variability in the non-freezing subgroup ($p = 0.02$). However, when freezing episodes were excluded from analyses, the mean stride time (cadence) did not differ between these two PD subgroups. In the aforementioned study, the two subgroups had different UPDRS motor scores ($p = 0.01$), which may attribute to the increased gait variability seen. Findings from Hausdorff and colleagues (2003) support the fact that the regulation of walking becomes worse as the disease progresses to a higher frequency and severity of freezing – especially just prior to and after a freezing episode.

Building on the aforementioned findings, a recent study investigates gait abnormalities of freezers (aged 64.4±8.7 years; 85.7% women) who had a disease duration of 7.5±4.5 years, compared to matched non-freezers (Weiss et al. 2014). Those with FOG had higher H&Y scores (3.2±0.8) than the non-freezers (2.4±0.5; $p<0.01$); however, no differences were seen between the two groups for MDS-UPDRS III. Participants were monitored constantly for three days to assess their quantity and quality of movement. Over the three days, the two groups had similar quantity of walking. In contrast, freezers had more impaired gait regularity ($p < 0.01$) indicated by both anterior-posterior and medio-lateral variability. Even the best gait parameters over the three days yielded between group differences for stepping variability, with the FOG group constantly showing worse walking quality ($p < 0.01$). Hence, gait disturbances found in those with FOG, do not only relate to the freezing episode itself, but also to their typical, best and

worse walking performance over these three days (Weiss et al. 2014). Apart from the regulation of walking, kinetic variables are also more severely affected in PD individuals who freeze.

Albani and colleagues (2014) considered kinematic variables and reported the differences found in joint ranges between PD freezers and non-freezers (participant characteristics are previously reported). PD non-freezers showed greater ankle dorsiflexion during the stance phase of the GC, while freezers where characterized with more flexion at the hip at initial contact and reduced hip ROM in the stance phase ($p < 0.05$). The proximal limp involvement seen in PD individuals with FOG indicates 'pelvic step' failure and trunk rigidity. During normal walking, pelvic rotation contributes to the scaling of SL and the consequent SV. This region changes between being more in-phase with thoracic rotation to one in which it is more out of phase. Poor pelvic-thoracic rotation, as seen in individuals with PD, contributes to failure in the above mentioned mechanism. Individuals with PD adapt the timing of the thorax rotations to that of the pelvis which produce walking slowly with small steps. Along with this biomechanical impairment, PD individuals lose their active breaking capacity. These difficulties are even more pronounced in PD individuals with FOG (Albani et al. 2014).

From a physiological point of view, Hausdorff and colleagues (2003) speculated that FOG may occur due to severely impaired synchronization of leg muscle activation where agonist and antagonist muscles are activated simultaneously. This may also be the mechanism responsible for impaired gait variability, but in a less severe form. Therefore, FOG may be the result of more severe unsynchronized muscle activation than that occurs during gait variability. FOG may also stem from compensatory gait adaptations when inadequate movement amplitudes are generated, lead to a reduction in step length and, when superimposed, cause a freezing event. It is suggested that this sequence of events leading up to a freezing episode may be caused by a mismatch between intention and automation of the SMA and basal ganglia (Snijders et al. 2011). Albani et al. (2014) considered the FOG phenomenon in PD as the clinical expression of cortico-subcortical interplay dysfunction. This has been deducted from the responsiveness of freezing episodes to external cues as well as its correlation with motor planning deficits and executive dysfunction.

Snijders et al. (2011) conducted a study on individuals with PD (participant characteristics are previously reported) and a healthy control group where they used motor imagery and MRI to investigate cerebral correlates of gait planning in individuals with PD with and without FOG by performing actual and imaged walking tasks. There was a correlation between actual and imaged walking times in both the control ($\rho = 0.78$) and PD group ($\rho = 0.54$) as well as for both PD

freezing ($\rho = 0.77$) and non-freezing ($\rho = 0.53$) subgroups separately ($p < 0.01$). Parkinson's individuals who do not freeze have larger activity in the SMA during motor imaging than during the same motor task. In contrast, those who experience FOG did not show significant larger activity in the SMA during motor imaging than during the task itself. Snijders et al. (2011) suggest that the cause of FOG may be due to changed cortical regulation of movement execution as well as impaired ability of mesencephalic motor areas to flexibly compensate for this alteration, which worsens as the disease progresses.

The above mentioned findings indicate the difficulty individuals with PD, especially those who freeze, have with diminished gait stability and reduced gait rhythmicity (Nieuwboer et al. 2007; Plotnik et al. 2005). The loss of gait pattern synchronisation in individuals with PD who freeze may be seen as the primary underlying neurophysiological mechanism of FOG (Bloem et al. 2004). Due to the more extreme decrements in individuals with PD who freeze, they have an increased risk for falls, nursing home admission and mortality. Research suggests the incidence of falls, in individuals with PD, is a function of disease duration and severity (Almeida et al. 2014).

Up to 40% of individuals with PD may experience falls and about 10% of them fall on a weekly basis (Nagal & Singla 2016). Bloem et al. (2004) reported that forward falls occur 45% and laterally directed falls occur 20% of the time. These reported values indicate the high incidence of falls in this population and highlights the effect it can have on PD individuals, their family and the community; especially if it leads to injuries. Unfortunately, it appears that PD medications do not reduce the incidence of falls (Allen et al. 2010). Consequently, individuals with PD, who are fallers, have an increased fear of falling compared to non-fallers (Cole et al. 2010). The prevalence of fear of falling can range from 35% to 59% of individuals with PD (Nilsson et al. 2012). Non-motor complications such as low levels of balance confidence, low fall-related self-efficacy and activity avoidance may also relate to fear of falling (Vandenbossche et al. 2011). If fear of falling leads to mobility restrictions and social isolation, it will contribute to functional decline and thereby reduce their QoL; consequently increasing their fall risk. This highlights the important role that physical exercise play in reducing fear of falling due to these contributing factors.

Form the aforementioned literature, it is clear that FOG is associated with balance and lower limb impairments and presents with different gait patterns than those who do not freeze (Bovonsunthonchai et al. 2014). These gait abnormalities indicate that individuals with PD, who freeze, lost their locomotion rhythm. Therefore, the loss of gait pattern synchronisation in

individuals with PD who freeze may be seen as the primary underlying neurophysiological mechanism of FOG (Bloem et al. 2004). Considering that FOG mostly occurs during functional activities such as walk initiation; straight, unobstructed walking; turning; negotiating narrow spaces or obstacles and when reaching a target (particularly in crowded places and during time-restricted, stressful situations), it is clear that FOG has a major impact on PD mobility (Bloem et al. 2004). This negatively affects their ability to properly move about to perform daily activities and increases their fall risk. Therefore, the PD freezing phenomenon is an important aspect to consider when addressing PD mobility. Taken together, individuals with PD generally have mobility impairments and those with FOG show more severe impairments. More specifically, those with FOG find the integration of visual and proprioceptive feedback during a motor task more difficult (Pieruccini-Faria et al. 2014) and show more severe progression in postural control impairments (Vervoort et al. 2016). Motor blocks, may occur due to an overload of processing resources from the cognitive, sensorimotor and limbic systems to the basal ganglia when insufficient dopaminergic demands are present (Beck et al. 2015). Apart from during normal walking, this mismatch generally also occurs during gait initiation, turning and obstacle negotiation. Freezing episodes often lead to falls, which may increase fear of falling, restrict participation in ADL and decrease QoL.

2.6.5 Turning

Turning, defined as a change in walking direction, is much more difficult for the neuromuscular system to perform than straight walking (El-Gohary et al. 2013; Manciniet al. 2015). The ability to change direction and turn safely is an important contributor to functional independence and, if impaired, can contribute to mobility difficulty and falls. With normal ageing, sensorimotor deficits cause turning to gradually become more difficult. Individuals with PD particularly have difficulty with turning (El-Gohary et al. 2013). More than halve of individuals with PD experience turning difficulties (Earhart & Falvo 2013).

One of the major motor impairments in individuals with PD is their inability to successfully execute a turn. Compared to the healthy population, PD individuals perform shorter turns with smaller angles and more steps, which is an expression of impaired bilateral coordination. Coupling between posture and gait as well as frontal lobe cognitive and executive function play an important role in postural transitions such as turning (El-Gohary et al. 2013).

In contrast to normal walking where both legs receive similar motor demands, turning requires different motor demands for each lower limb, i.e. the priority of one leg is primarily pivotal, which complicates the bilateral coordination between the lower limbs during turning (Plotnik et

al. 2005). Hypokinesia usually occurs during turning in individuals with PD and presents as slowness of movement with multiple small steps, resulting in an en bloc turning technique with little movement between body segments (Canning et al. 2006). An en bloc turning technique may contribute to fall risk and may expose PD individuals to akinetic blocks, also known as FOG (Earhart & Falvo 2013; El-Gohary et al. 2013). As mentioned earlier, FOG triggers often contribute to fear of falling. Apart from walking difficulty itself contributing to fear of falling, other factors affecting PD individuals' fear of falling while walking include balance impairments, difficulty climbing stairs and turning hesitations (Cole et al. 2010; Nilsson et al. 2012).

El-Gohary et al. (2013) monitored twelve PD individuals (aged 65±6.0 years) with UPDRS motor score of 24.5±7.5 (other demographic characteristics were not reported) and matched healthy controls at home over seven days, for an average of ten hours per day. Both groups performed a similar amount of turns per hour ($p = 0.45$). All turns during the week were categorized in slow, normal or preferred and fast turning speeds. In all these categories, the PD group had slower turning velocity; however, turning duration did not differ between the groups over the three categories (p-values not reported). When analysing all turns grouped together, the PD groups demonstrated lower turning duration, angle and peak velocity as well as a lower number of steps during a turn (all $p < 0.01$).

Mancini et al. (2015) performed a similar study and compared at home turning variables with 90 and 180 degree turns during a lab-based gait task, to report on quality and quantity of turning in PD individuals of the same age and UPDRS III scores with matched control individuals. Participants in this study had a disease severity of 2-4 on the H&Y scale, with no other characteristics reported. In line with the previous findings, there were no between group differences for the number, i.e. quantity, of turns, indicating a similar level of activity ($p = 0.45$). Regarding the quality of turning, the PD group, as with the previous study, had impaired turning velocity and step number compared to the control group, which also correlated with UPDRS motor scores (both $r = 0.61$; $p = 0.03$). A novel finding in this study was the turning variability within and across days over the week, which also correlated with UPDRS motor scores, reflecting the effect of functional impairments on turning ability ($r = 0.79$; $p = 0.01$). These findings support the idea that PD rather affects the quality of turning characteristics than the quantity of turns (Manciniet al. 2015).

Limitations in turning abilities observed in individuals with PD occur due to a combination of perpendicular and axial deficits. Research suggests that axial deficits may drive secondary

responses in the limbs (perpendicular body parts) during turning in individuals with PD (Vandenbossche et al. 2011). Axial deficits, i.e. muscle rigidity, generally do not improve with the use of levodopa and is therefore ineffective for turning performance (Hulbert et al. 2014). Hence, this highlights the importance of alternative interventions to improve turning performance to thereby reduce the risk and fear of falling.

a) Perpendicular deficits

Perpendicular deficits can be defined as "non-optimal movement occurring in any aspect of the perpendicular areas of the body, such as the limbs" (Hulbert et al. 2014, p. 2). Perpendicular and voluntary movements are controlled by the cortico-spinal tracts. Perpendicular deficits are evident in the step number, step length and strategy used by PD individuals while executing a turn.

Step number is often related to disease severity (UPDRS score) with an increase in the number of steps taken to complete a turn as the disease progresses (Manciniet al. 2015). Step number is affected to an even greater extent when turning in the un-preferred direction or in unfamiliar surroundings (Cheng et al. 2014). Mancini et al. (2015) reported that the PD individuals in their study took an average of 3.2 steps compared to 1.7 steps taken by the control group. An increase in the number of steps taken to complete a turn is indicative of their turning difficulty and inefficiency (Manciniet al. 2015). However, due to PD related postural instability and limited axial rotation, an increased step number during turns might be a compensatory strategy to maintain functionality (Hulbert et al. 2014). Therefore, an increase in the number of steps taken to complete a turn indicate poor turning performance, but on the other hand, act as a beneficial tool for PD individuals to reduce their risk of falling and to maintain functional independence. El-Gohary et al. (2013) highlighted that PD individuals have a 50% increased risk of falling and that most falls occur while walking and turning. Falls are eight times more likely to cause a hip fracture, compared to falls during straight walking (Cheng et al. 2014).

Step length is usually reduced and may be related to less foot clearance. Compared to controls that decrease their step length by 22% during a turn, individuals with PD decrease their step length by 37% (Hulbert et al. 2014). Also, individuals with PD use a very tight turn strategy which reduces step length to an even greater extent. Even though reduced step length decreases turning accuracy and efficiency and may result in hypokinesia or freezing, it might be a compensatory adaption of these individuals to maintain postural stability with a wider base of support during the turn to keep their centre of gravity central to their base of support. This

adaptation enables individuals with PD to maintain functional balance to safely complete a turn (Hulbert et al. 2014).

The turning strategy used by PD individuals changes from a spin or step round strategy (where the target is directly approached while walking) as seen in healthy elderly individuals, to an incremental (turning on-the-spot) strategy (Hulbert et al. 2014). The incremental turning strategy is adopted during the early disease stages possibly to preserve postural stability (Song et al. 2012). This is shown during walking turns where PD individuals use a smaller turning angle and a narrower step width than healthy individuals (Song et al. 2012; El-Gohary et al. 2013; Manciniet al. 2015). The change in turning strategy from a spin turn to a multiple step pattern to reduce instability with disease progression is further supported by the related increase in UPDRS motor symptoms and reduced balance confidence on the ABC scale (Hulbert et al. 2014).

To summarise perpendicular deficits, reduced step length, increased step number and an altered turning strategy labels the difficulty these individuals have to execute a turn. It is not clear whether these adaptions occur primarily due to disease physiology or secondary in attempt to gain greater stability while turning.

b) Axial deficits

Axial deficits can be defined as “non-optimal movement occurring in any aspect of the axial areas of the body, such as the head, shoulders, trunk and pelvis” (Hulbert et al. 2014, p.2). Axial structures play an important role during mobility as the musculature of these structures connects all body parts. Axial musculature is responsible for automatic postural reflexive movements as well as postural control. The regulation of postural control by the axial musculature provides a stable base of support for the coordination and control of perpendicular limb movements. However, in individuals with PD, axial motor functions are excessively controlled to lead to axial segment rigidity and ultimately postural changes (Hulbert et al. 2014).

Increased segment rigidity with disease progression influences the deficit in scaling ability of segmental rotation. Therefore, during turning tasks, increased axial rigidity is related to deficits in axial rotation and leads to the adoption of secondary compensatory strategies (Son & Kim 2015; Peterson & Horak 2016). Moreover, Hulbert et al. (2014) suggests that axial rigidity can furthermore be divided into body segment coordination, timing and rotation deficits.

Individuals with PD have altered segmental coordination and timing during turns which presents with delayed segment onset, velocity and total time of the turn. Also, there is a delay in coordination between pelvis and foot movement which might occur due to different control

mechanisms of these two segments. These alterations negatively influence the coordination between axial and perpendicular structures during turning. Thus, in compensation, the coordination of movement during a turn is simplified to one degree of freedom to produce an en bloc turn. This lack of coordination between body segments brings forth the perception of instability which may lead to the adoption of a rigid trunk for stabilization of limb movements (Hulbert et al. 2014).

Also, in PD individual segment rotation is reduced around each footstep during a turn. In contrast to healthy individuals who first rotate their pelvis around the vertical axis, before moving their feet in order to execute a turn; the trunk and pelvis of PD individuals move together as a unit, resulting in limited rotation around the vertical axis before the feet must move (El-Gohary et al. 2013). Therefore, an increased number of steps and decreased step length is observed. This might be linked to the delayed segmental initiation and decreased velocity during a turn, leading to secondary, compensatory step strategies (Hulbert et al. 2014).

Lastly, postural changes are observed with PD individuals' forward trunk inclination. Trunk and hip flexion as well as knee flexion during turning occurs as a primary disease response (disturbances in neurotransmitters) as well as from secondary non-neural musculoskeletal adaptions which are related to axial rigidity (Son & Kim 2015; Peterson & Horak 2016). Even though postural changes might occur as compensation to a lack of stability, this altered posture changes the position of centre of mass over the base of support to cause instability which is especially experienced during turning (Song et al. 2012).

To summarize axial deficits, segment rigidity mainly contributes to PD individuals' turning difficulty. This characteristic stiffening of the body leads to an en bloc movement pattern during turns. More specifically, coordinative deficits, delayed segmental timing and reduction in segmental rotation influences postural control while turning.

2.6.6 Functional capacity

Functional capacity gives an indication of an individual's ability to perform independent daily activities that require sustained aerobic metabolism (Arena et al. 2007; Sugiura et al. 2016). As FC is affected by cardiovascular, pulmonary and skeletal muscle function and is a strong prognostic factor (Fernandes-Silva et al. 2017), it is often synonymously used with exercise capacity and exercise tolerance (Arena et al. 2007). Changes in FC have a direct relationship with independence and QoL, especially in the elderly (Sugiura et al. 2016) and therefore is a good indicator of mobility and predictor of fear of falling (Curtze et al. 2016). In PD, improved

FC has shown to be related to executive function (Miura et al. 2015). Other components of FC include coordination, balance, flexibility and agility, which all are important for PD mobility (Orcioli-Silva et al. 2014). In elderly populations, a 6MWT is generally used to determine FC to illustrate their ability to sustain a certain velocity for several minutes and give an indication of their state of conditioning. From this, FC is expressed as a sub-maximal indication of aerobic capacity or endurance (Steffen & Seney 2008). Thus, changes in FC can be due to any, or a combination, of these aforementioned factors. It is well known that impairments in these components severely affects gait and mobility, especially in PD (Herman et al. 2009).

The study done by Canning and colleagues (2006) showed that the PD group could not sustain high enough velocities during the 6MWT to achieve comparable walking distances with the control group, indicating decreased FC. A trend analyses however found that the PD group did not show deterioration of spatiotemporal parameters (velocity, $p = 0.20$; stride length, $p = 0.14$ and cadence, $p = 0.54$) as the minutes went by during the 6MWT.

In PD, not only the disease itself, but also aging affects FC. PD individuals in their seventies (aged 74.7 years; 13% women) who had a H&Y score of 2.7 and disease duration of 6.2 years (no standard deviations reported) walked 461.5±94.8m in six minutes (Schenkman et al. 1997). Furthermore, Garber and Friedman (2003) reported a mean 6MWT distance of 395.1±141.6m in PD individuals in their sixties (aged 64.0±10.0 years; 30% women) who had a H&Y score of 2.1±0.7 and disease duration of 2.4±1.8 years. A more recent study done by Canning and colleagues (2006) reported a decrease in 6MWT distance in individuals with PD compared to healthy elderly ($p = 0.01$); however, the mean distance of PD participants was 546±103m which is more than the previously mentioned studies. Discrepancies between these three studies may be due to different instructions used during the 6MWT protocol with regards to the speed of walking, age of participants, heterogeneity as well as disease duration. The aforementioned values are lower than that of healthy age-matched individuals and may be contributed to hypokinesia, impaired automaticity or reduced muscle strength.

During the 6MWT done by Canning and colleagues (2006), no differences were found in heart rates (HR) ($p = 0.98$); however, leg muscle fatigue (peak isometric knee extensor torque) was significantly greater in the PD group ($p < 0.01$). Furthermore, correlations between 6MWT distance and hypokinesia during walking ($r = 0.96$; $p < 0.01$) and turning ($r = –0.61$; $p < 0.01$) as well as strength ($r = 0.55$; $p < 0.03$) have been reported, but no correlation were found between 6MWT distance and automaticity (which were the velocity during dual task walking expressed as a percentage of velocity during single task walking) ($r = –0.07$; $p < 0.79$). Hypokinesia,

turning and strength accounted for 94% of the variance seen during the 6MWT ($p < 0.01$). However, independently, only hypokinesia during walking contributed significantly to 6MWT distance ($p < 0.01$), with hypokinetic turning ($p < 0.63$) and strength ($p < 0.28$) showing no significant independent contributions (Canning et al. 2006). Also, reduced automaticity during short distance walking at a comfortable speed did not correlated with automaticity during the 6MWT, making automaticity an irrelevant contributor to FC in individuals with PD. This finding indicates the importance of correcting hypokinetic gait in individuals with PD to promote FC.

Comfortable walking velocity, when individuals with PD walk long distances, is lower than the fast-as-possible walking speed over shorter distances; which may result in deconditioning over time. This deconditioned state has been shown in the PD group by Canning and colleagues (2006) who found similar HR ($p = 0.98$) and breathlessness ($p = 0.19$) scores compared to the control group, but with greater fatigue scores ($p < 0.01$) and shorter distances covered ($p = 0.01$) in the PD group.

Aerobic exercise is an important rehabilitation component for individuals with PD as impaired cardiovascular function severely affects gait and mobility (Herman et al. 2009). A physical activity regimen that induces improved FC, especially at fast speeds, is of importance in individuals with PD to delay their inevitable deconditioning. Falvo and Earhart (2009) stated that training for PD individuals that target improving balance and reducing falling risk factors may increase the distances walked in the 6MWT (i.e. walking capacity). If this could be achieved by backward walking (BW), PD individuals' primary motor control impairment, hypokinesia, can be improved while also improving FC and QoL (Canning et al. 2006).

2.6.7 Summary

From the aforementioned subsections it is clear that individuals with PD experience a wide variety of mobility impairments, i.e. in spatiotemporal parameters which include gait cycle, joint ranges and arm swing deficits as well as in FC. As the disease progress, these symptoms worsen and expose many PD individuals to the debilitating freezing phenomenon. Whether a freezer or not, individuals with PD show continues detrimental locomotive variables with disease progression, especially during movement initiation, turning and obstacle negotiation.

From a clinical point of view, a variety of rehabilitative strategies can be used to improve mobility performance in individuals with PD by focussing on improving axial deficits as well as deficits in the perpendicular body segments (Vandenbossche et al. 2011). Equally important, individuals with PD with FOG should be taught not to try and overcome motor blocks during

walking, as this might increase their risk of falling (Bloem et al. 2004). Despite the many suggestions on how and why PD-related deficits occur, the exact neurophysiological mechanisms need explorative investigation in attempt to shed light on the uncertainties and the unknown. Also of importance are strategies to improve PD mobility to consequently delay the progression of disease-related impairments.

2.7 Backwards Walking

In recent years, BW and running has become an attractive exercise alternative for training and rehabilitation purposes. This is due to the possible benefits that a BW training regimen may have. Backwards walking is generally more difficult than FW due to reduced postural control and no visual cues as well as the unfamiliarity thereof (Blazkiewicz 2013). However, compared to FW, BW may be a useful tool in terms of muscle and neural activity that is increased to achieve motor learning (Lee et al. 2013). For example, BW may have a positive effect on balance, as visual input during BW is reduced and other sensory information must be relied on. Also, BW can promote a more erect posture as less trunk inclination is evident during this walking direction (Grasso et al. 1998).

This places the use of BW in neuro-rehabilitation in perspective. Individuals with neurological disorders, such as stroke (Yang et al. 2005) or cerebral palsy (Kim et al. 2013), have previously benefited from BW during gait training in attempt to improve components of forward mobility. From this point of view, BW is used to induce motor learning and reduce gait irregularities. Unfortunately, the mechanisms for transferring improvements in BW to FW are poorly understood (Hoogkamer et al. 2014).

Compared to FW, the mechanics of BW differ in terms of foot contact with the toes and lift-off with the heel in the end of the stance phase during BW (Blazkiewicz 2013). This section elaborates on several considerations associated with BW, i.e. biomechanical, physiological and neural considerations as well as on the clinical application of BW. Finally, this section elaborates on BW in PD.

2.7.1 Biomechanical Considerations

Due to anatomical constraints, it is difficult to walk at the same speed forward and backward, for any given perceived effort. Anatomical constraints during BW exist due to the structure of the ankle, knee and hip joints (Grasso et al. 1998; Blazkiewicz 2013). Despite anatomical constraints, the support:swing ratio (60:40) of a walking stride is similar during BW than during FW However, at similar velocities, BW generally presents with a shorter SL and a greater SV

compared to FW. Also, BW induces an increased stride rate and more time spent in the support phase of the GC (Grasso et al. 1998).

Laufer (2005) investigated differences in BW abilities between young (aged 24±2.3 years) and elderly (aged 77.7±6.2 years) healthy individuals. Similar to FW, BW showed an age-related decrease in gait velocity, SL and swing phase time as well as an increase in double support phase time; however, cadence was unaffected with the reversal of walking direction ($p < 0.01$). The aforementioned findings were true during both normal and accelerated walking speeds (Laufer 2005). Furthermore, BW presents with more variability than FW. This is evident with stride time, SL, knee and hip ROM as well as the relative stance phase that are more variable during BW compared to FW (Hoogkamer et al. 2014). Therefore, one needs to consider a familiarization period to allow individuals to become accustomed to BW as a training task.

Due to the changes in joint functions with BW, the joint power patterns of the ankle, knee and hip joints are different compared to FW. The main propulsion and shock absorption joint during BW is the ankle joint as this is where the largest joint moment and power is generated (Lee et al. 2013). Therefore, the ankle is very important to propel the body backwards. Changes in joint functions also affect muscle activity around those joints.

With BW, there is a modification of lower extremity muscle activity, where the musculature that supports the ankle and knee joints is reversed with BW (Grasso et al. 1998). More specifically, muscle action of knee extensor muscles is mostly eccentric and concentric during forward locomotion and during backward locomotion, muscle action changes to isometric and concentric actions (Hoogkamer et al. 2014). Eccentric contractions are more stressful for this muscle group. Therefore, BW place less biomechanical strain on the knee joint than FW (Laufer 2005; Woo et al. 2009). Apart from the novelty of BW, changes in muscle functions may affect physiological outcomes of BW compared to FW.

2.7.2 Physiological Considerations

Backwards walking generates greater stress to the cardiovascular system compared to FW, when performed at a similar velocity than FW (Grasso et al. 1998; Terblanche et al. 2005; Woo et al. 2009), which may be attributed to considerably greater muscle activity during BW than during FW, in proportion to effort (Woo et al. 2009; Blazkiewicz 2013). Consequently, HR and VO_2 can be up to 78% and 47%, respectively, higher in BW than in FW at the same speed (Masumoto et al. 2007). BW is also considered for aerobic training as this activity increases energy expenditure to levels high enough to maintain cardiovascular fitness (Laufer 2005). Individuals

with PD may benefit from aerobic exercise due to the increased release of neurotropic factors which promotes neuron survival, differentiation and growth. These changes promote brain health and equal neuroplasticity in the central nervous system to thereby induce mobility improvements in individuals with PD (Rosenfeldt et al. 2015). In order to induce neuroplasticity through exercise, interventions should be intense and continuous.

As BW is a novel movement pattern, it can be expected that physiological demands may change over time. By becoming more accustomed by the skill of BW, the physiological effort necessary to perform the task is reduced. Results from Terblanche et al. (2005) suggested that the physiological demands of BW can be reduced after 12 exercise sessions. However, as this study was performed on healthy women aged 21.0±0.8 years, it can be expected that physiological changes takes longer in elderly individuals.

It is suggested that the the neuromuscular system is upregulated with BW and thereby increase input to muscle spindles and proprioceptive systems. Therefore, pressure receptors within the muscles, vestibular system and skin are stimulated to thereby increase muscle activity. Consequentely, training in a novel tasks such as BW may be important for individuals who have impairments in these aformentioned systems (Masumoto et al. 2007).

2.7.3 Neurological Considerations

It is suggested that FW and BW are generally largely controlled by the same basic neural mechanisms but with additional circuits that are specific to FW or BW. Even though research suggests that BW is at least partly controlled by specialized neural circuits, transfer of gait outcomes from BW training to FW has been shown in post-stroke patients (Yang et al. 2005). Whether such improvements can be achieved by individuals with PD, is evident to investigate.

Some features of gait are strongly controlled by the cortex. In the general population, BW requires larger activation of the primary motor cortex, SMA, parietal cortex, thalamus, putamen and caudate but less activation in the cerebellum and brainstem. The motor cortex is especially important for the control for stability as such challenges activate this area in the brain more so during BW than during FW. Due to the associated lower dynamic stability of BW, it is a more demanding task and requires more neural input from the motor cortex (Hoogkamer et al. 2014).

Furthermore, due to the novelty of BW, it is generally less automated than FW. Also, the visual-spatial processing and sensorimotor control required for BW activates higher levels of the cortical areas. Considering that postural instability is a hallmark of PD, increasing activity in the motor cortex, i.e. with BW training, may enhance the control of stability.

It is thus curious whether a training regimen, such as BW, that activates separate neural structures than that of a more automated movement, such as FW, may improve impairments that are associated with the same neural structures, such as those seen with PD.

2.7.4 Clinical implication

Backwards walking is a task that is simple in description and action, but complex in its potential benefits. Benefits from BW can be explained by improved aerobic fitness, musculoskeletal properties or due to neural gains (Lee et al. 2013). It can be expected that improvements in aerobic fitness as well as muscle strength and flexibility translate to other activities that place similar demands on these systems. On the other hand, neural structures could explain any improvements in tasks that are less physically demanding (Hoogkamer et al. 2014).

Improvement in aerobic fitness may also improve mobility. Aerobic exercise has been reported to improve FC as well as movement initiation, which both may improve overall mobility in PD individuals (Toole et al. 2005). Mechanisms by which aerobic exercise promote neuroplasticity in the central nervous system, to thereby induce mobility improvements in individuals with PD, is suggested by Earhart and Falvo (2013) as well as Rosenfeldt et al. (2015).

The increased knee extensor activation during BW may help to restore the ideal 60:40 strength ratio between the quadriceps and hamstring muscles. By realigning this ratio closer to the ideal, one can prevent possible knee injuries. However, research does not suggest that BW results in faster strengthening of the quadriceps muscle compared to conventional strength exercises (Hoogkamer et al. 2014).

Hamstring flexibility, as measured by the sit and reach test, have also been reported to increase after a four-week BW intervention as was highlighted for athletes (aged 21.2±5.1 years) who experienced low back pain (Dufek et al. 2011). However, this study did not include a control group that performed FW to compare the results. Furthermore, BW can be used to increase motor control by changing the emphasis on foot placement. As the foot is placed behind the body with BW, hip extension and knee flexion is facilitated (Hoogkamer et al. 2014). Therefore, BW provides an alternative exercise regimen that those with a limited functional ROM (such as some individuals with PD) may exercise without straining themselves beyond their functional capabilities and by doing so, possibly release rigid muscles through reciprocal inhibition. It might be possible with BW in PD to combat disease-related rigidity, especially around the pelvis.

Apart from biomechanical benefits, BW challenges the neuromuscular system as well as postural control. With BW, a complete view of the road ahead is obstructed. It is thus required of the

backwards walker to rely more on other senses such as auditory and sensory systems, than on the visual system (Hoogkamer et al. 2014). Backwards walking could be helpful for motor learning caused by the modification of neural mechanisms (Lee et al. 2013). The motor learning mechanism is important to re-educate impaired musculoskeletal function. Therefore, to become more efficient in BW; kinaesthetic sense, proprioception and balance need to become more developed. Equally important, by walking in the reverse direction, plantar pressure is more evenly distributed compared to FW, which contributes to improved balance and coordinative abilities as well as muscle contractibility. Improved plantar pressure distribution has been shown in diabetics with peripheral neuropathy (aged 52.7±6.5 years), which may suggest the positive effects of BW on peripheral neural function (Zhang et al. 2014). This enhancement in balance and dynamic equilibrium may be beneficial especially for elderly individuals in the prevention of falls (Laufer 2005).

Backward falls are generally characterised by a rapid simultaneous increase in trunk extension and trunk extension velocity (Liu & Lockhart 2009). Therefore, training tasks that may allow an individual to have more control over these parameters, might aid them in the prevalence of backward falls.

2.7.5 Backward walking in Parkinson's disease

Individuals with PD have difficulty modulating a variety of mobility constraints. As many mobility tasks, especially gait, are multidirectional, the related constraints are much more complex. Therefore, investigations of mobility tasks should stretch beyond mere FW. Studies on BW in individuals with PD are however scarce (Hausdorff et al. 2003; Schaafsma et al. 2003; Springer et al. 2006; Peterson et al. 2012). *Table 2.2* summarises studies that focussed on BW in PD.

Hackney and Earhart (2009) were the first to examine BW in mild to moderate PD (aged 65.1±9.5 years; 28% women) compared to healthy controls (aged 65.0±10.0 years; 23% women). The PD group had a UPDRS III score of 27.5±9.2 and disease duration of 8.2±5.0 years. Compared to controls during FW, individuals with PD have decreased SL, lower swing percentage and higher stance percentage of the GC ($p = 0.02$). Both groups were also assessed while walking backwards. The aforementioned deficits during FW in PD were found to be even greater during BW than during FW. More specifically, decrements in walking velocity, SL, swing percentage and stance percentage of the GC during BW were beyond those seen during FW and were also worse when compared to controls ($p < 0.01$). Furthermore, gait variability was higher during BW compared to FW ($p < 0.01$) and an inverse correlation were found between UPDRS

scores and BW velocity ($r = 0.29$; $p = 0.01$) for the PD group (Hackney & Earhart 2009). Unfortunately, the authors of this study did not report any percentage differences.

Of the PD individuals investigate by Hackney and Earhart (2009), those with FOG had higher stance ($p = 0.03$) and swing ($p = 0.04$) percentage of the GC, longer SL ($p = 0.03$) as well as increased variability in stance ($p = 0.01$) and swing percentage of the GC. Moreover, Peterson et al. (2012) reported that the coordination of steps becomes even worse during complex gait tasks, such as turning and BW, compared to FW ($p < 0.01$) in PD freezers with H&Y score of 2.63±0.83 (aged 72±9 years; 8.0±4.5 years since diagnosis) compared to non-freezers (only differed in FOG-Q scores, $p < 0.01$). These findings might indicate the effect of disease severity and duration on the neural system. If different neural systems are used for BW and FW, they might be differentially affected by PD, even from the earlier disease stages and influenced by the disease process (Hackney & Earhart 2009).

Two years later, Hackney and Earhart (2011) reported on the effects of dual tasking (DT) during BW in the same population as used during their 2009 study. The previously mentioned BW parameters (velocity, SL, GC swing percentage and heel-to-heel base of support) of PD were even worse when a secondary, cognitive task was added, compared to the performance of the control group ($p < 0.05$). Also, the FOG group performed worse than the non-freezing group ($p < 0.05$). Unfortunately, the authors of this study did not report any percentage differences. Results from the aforementioned study illustrate the limited executive resources and less automaticity that this population has compared to healthy controls, especially under DT conditions.

Building on this, a study investigated differences between actual and imaged simple (FW) and complex (turning and BW) gait tasks. PD individuals with H&Y score of 2.34±0.33 (aged 64.9±7.6 years; 6.7±6.0 years since diagnosis; 42% women) and matched healthy control individuals were included (Peterson et al. 2013). Compared to controls, the PD group showed reduced activity in the globus pallidus across all three imaging tasks, which reflected their underlying gait dysfunction presented as decreased walking speed. Also, increased SMA activity was seen in PD individuals during imaged turning and BW ($p = 0.03$), but not during FW ($p = 0.06$). These findings support the compensatory neural changes during complex mobility tasks. PD participants in this study were tested during the off-state (Peterson et al. 2013).

Table 2.2 Summary of studies that investigated backwards walking in Parkinson's

	Hackney & Earhart 2009	**Hackney & Earhart 2011**	**Peterson et al. 2012**	**Bryant et al. 2011**
Participants	78 PD (H&Y 0.5-3.0) 74 matched controls Age: 65.1 ± 9.8 years	78 PD (H&Y 0.5-3.0) 74 matched controls Age: 65.1 ± 9.8 years	12 PD freezers (H&Y: 2.4 ± 0.4) 19 PD non-freezers (H&Y: 2.6 ± 0.8) 10 matched controls Age: 70.7 ± 9.7 years	21 PD H&Y: 2.8 Age: 70.2 ± 8.7 years
Aim	To assess BW in PD and healthy controls	To assess FW and BW with and without a DT	To determine phase coordination index during simple (FW) and complex (BW and turning) tasks	To investigate the effect of levodopa on FW and BW
Methods	5m walkway 3x FW and BW trials	5m walkway 3x FW and BW trials under ST and DT conditions	5-8x FW & BW on 10m walkway; 1x 60s large circle to left & right; 3-5x 20s small circle to left and right	FW and BW on a 3m walkway before and after taking levedopa
Findings	Impaired FW & BW gait paramters compared to controls. BW gait parameters worse than FW in both groups.	PD individuals were more affected with the DT than controls. Freezers were more affected with the DT than non-freezers. BW is more difficult than DT in PD.	Stepping coordination worse in freezers than non-freezers and controls. Complex tasks resulted in worse coordination than FW.	Levedopa improved gait paramters. Levedopa had a larger effect on FW than on BW. Cadence was not changed with levodopa.

Abbreviations: PD = Parkinson's disease; H&Y = Hoehn and Yahr score; BW = backwards walking; FW = forward walking; DT = dual task; ST = single task.

It is important to note that a previous study has shown that PD individuals imagine similarly to older adults during both on- and off-state of medication usage (Peterson et al. 2012). However, the imaging results during actual motor tasks that were performed during the off-state should be carefully considered, as anti-Parkinson medication has an influence on motor tasks itself. This is

supported by improvements in BW gait parameters which were similar to FW, when PD individuals are in the on-state of medication usage, while no improvements are seen in cadence during both FW and BW (Bryant et al. 2011).The results from the aforementioned studies induced interest in the training of complex mobility tasks, i.e. BW, that might allow motor learning and what the functional outcomes on such a training regimen might be in PD individuals.

2.7.6 Summary

Comparing BW to FW, BW presents with a different foot contact pattern, reduced ROM in the lower extremity joints, an increased stride rate, increased physiological demands and different muscle firing patterns of the lower extremity musculature.

The biomechanical constraints of BW may limit the ability of elderly individuals to walk backward. Backwards training in young adults has shown motor learning, improved skill and reduced oxygen intake after 12-18 training sessions. The effect of training in the backward direction on elderly individuals however still leaves possible areas for investigation – especially the effect of BW on balance control, lower extremity strengthening and aerobic conditioning (Laufer 2005). Furthermore, the effect of BW on individuals with a variety of diseases has not yet been researched extensively. Of particular interest is the effect of BW on the mobility of individuals with PD.

2.8 Physical training for Gait in Parkinson's disease

Evidence has shown age-related decrements in neuromuscular function after 60 years of age which presents with mobility impairments and adverse health conditions. The average age of PD diagnosis also occurs during the sixth decade. Hereafter, diagnosed individuals experience larger magnitude and faster progression of age related impairments (Earhart & Falvo 2013). To combat this, interventions that induce neuromuscular improvements are of importance to individuals with PD.

Due to age as well as disease-related decrements in balance and gait, fall risk is magnified in individuals with PD. A high annual fall rate of 70% in individuals with PD contributes to the most common cause of hospital visits for these individuals (Earhart & Falvo 2013). These high fall rates call out for interventions to minimize the risk factors associated with falls. Benefits from exercise suggested in literature reinforce the concept of 'exercise is medicine' for individuals with PD as improvements in motor symptoms, balance and QoL is seen with many physical therapy interventions (Rosenfeldt et al. 2015).

Over time, both motor and non-motor functions show progressive impairments and limitations that restrict PD individuals' ability to participate in many ADL (Bloem et al. 2004). More specifically, these functions are affected by FOG, impaired balance and cognitive decline. This highlights the importance of physical therapy as part of the Parkinson's management plan. As posture, balance, muscle strength, gait and transfers are of importance for autonomy in functional mobility tasks, these qualities are good targets for rehabilitation (Monteiro-Junior et al. 2015).

Physical activity has shown to have major positive impacts on PD life. The neurobiological mechanisms by which exercise may benefit individuals with PD have recently been proposed (Earhart & Falvo 2013; Monteiro-Junior et al. 2015; Rosenfeldt et al. 2015). A wide variety of treatment modalities can be used to improve mobility and reduce falls. Some of these strategies include auditory and visual cueing techniques to improve gait parameters and FOG; gait training; cognitive movement strategies; alternative strategies to perform safe transfers, as well as other physical activities to improve postural stability, flexibility and general fitness (Bloem et al. 2004; Snijders et al. 2010).

Training for individuals with PD to improve mobility includes a combination of ROM, activity related gait and balance exercises, resistance training and cardiovascular exercise. Peppe et al. (2007) performed a study on individuals with PD (aged 6.5±9.8 years of which 63% were women) and matched healthy controls. The PD group had a disease severity of 2.3±5 on the H&Y scale and disease duration of 6.7±4.2 years and all of them were hospitalised. Participants in this study performed a total of 66 hours of physical therapy in eight weeks that consisted of comprehensive rehabilitation focused on the different domains of physical therapy – flexibility, strength, balance and gait. With this combination of exercise types, the PD group improved their natural walking speed, which was attributed to improved SL and cadence ($p < 0.01$). After the rehabilitation program, individuals with PD also showed improvements in stance percentage of the GC with a decrease from 68.1% to 65.6%, swing percentage of the GC with an increase from 32% to 34.4%, SV and swing velocity (all $p < 0.01$). Step width and percentage double support time did not show any differences between pre and post testing. Peppe et al. (2007) also investigated kinematic gait variables before and after the rehabilitation program. Joint ranges during the GC only showed improvements for the ankle ($p = 0.02$) and knee joints during the swing phase ($p < 0.01$), with no differences in joint ranges during the stance phase. Because of the combination of exercises used in this training program, it is not clear whether the improvements were due to a specific exercise modality or just due to the addition of exercise

itself. Nonetheless, findings from the aforementioned study show the importance of rehabilitation for individuals with PD.

It is however curious what the effect of interventions that require high levels of neuromuscular activation might be on mobility. Training that enhances gastrocnemius contraction (such as BW training) may be beneficial for PD gait, especially for the push off phase of FW. From this point of view, BW might help to restore the shift in lower limb muscle activation by concentrically activating the extensor muscles (Hoogkamer et al. 2014) and hereby possibly release the flexor muscles through reciprocal inhibition.

2.8.1 Potential benefits of exercise

Several studies have shown the positive effects of physical exercise in the synthesis of neurotransmitters to thereby improve PD symptoms. More specifically, it is suggested that the increased serum calcium levels associated with exercise may stimulate dopamine production (Earhart & Falvo 2013). Furthermore, physical activity increases neuro-protective antioxidants and enzyme activity to combat oxidative stress (Rosenfeldt et al. 2015). These responses occur in a dose-response relationship that presents with a J-curve, where optimal results are found with moderate to high intensity training (Monteiro-Junior et al. 2015). *Figure 2.5* illustrates a summary of the role that exercise plays in neuroplasticity in PD.

Furthermore, some studies have found increased dopamine concentration as well as enhanced signalling to other neurotransmitters with exercise (Rosenfeldt et al. 2015). Increased cerebral blood flow during exercise might create the optimal environment for angiogenesis as well as dopamine synthesis at pre-synaptic neurons and post-synaptic receptors in the *substantia nigra* (Monteiro-Junior et al. 2015). Exercise appears to increase the synthesis of important proteins and trophic factors in neural pathways that might promote neural growth and reduce the vulnerability of dopamine cells to decrease disease progression by stabilizing and improving PD symptoms (Earhart & Falvo 2013; Rosenfeldt et al. 2015). These mechanisms were derived from a variety of exercise modalities, including resistance and cardiovascular training as well as training strategies that enhances balance, flexibility and coordination, for example, dancing.

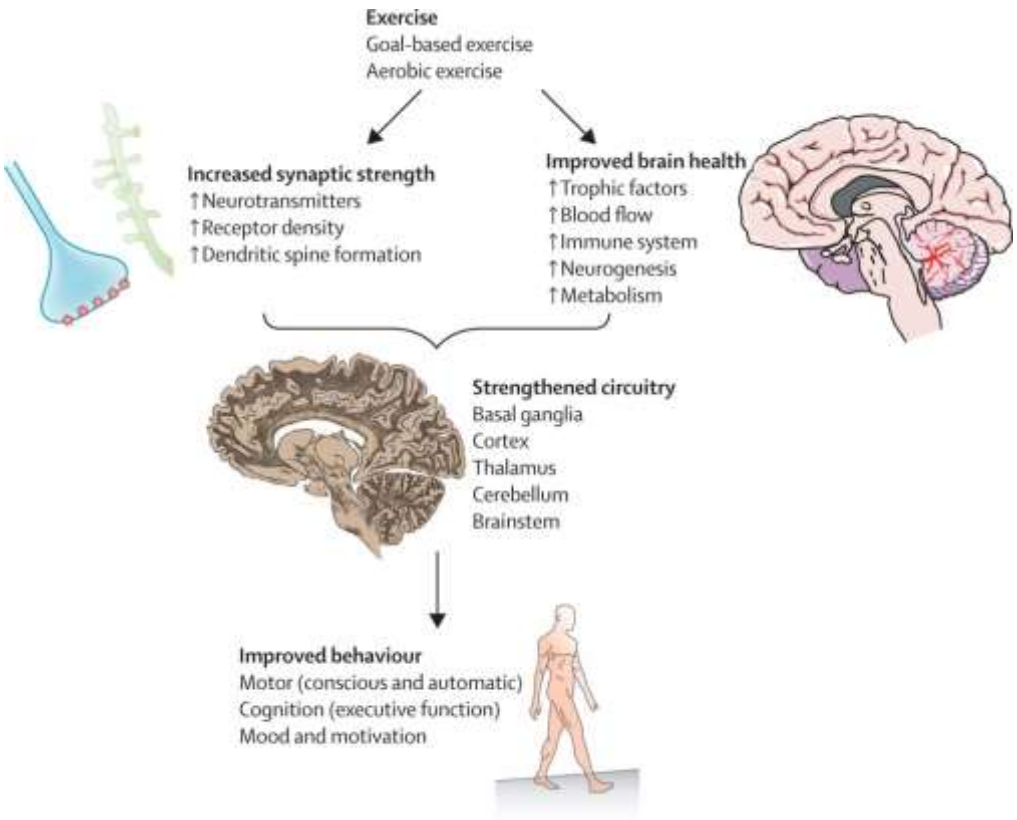


Figure 2.5 *Diagram illustrates how exercise can induce neuroplasticity in Parkinson's disease. Exercise leads to improved brain health in general that allows enhanced neural circuitry between the basal ganglia and thalamus. In turn, this leads to improved behaviour in Parkinsons* (Petzinger et al. 2013)©.

Strength of the lower limb muscles plays an important role in the control of upright stability in individuals with PD to thereby reduce fall frequency (Toole et al. 2005). Impaired force production in PD is suggested to be related to under-activation of the cortical motor centres and the inability to fully recruit motor neurons of the working muscle (Earhart & Falvo 2013). A 2013 review summarized several studies that induced significant improvements in force production, muscle endurance, muscle size, gait performance, balance, mobility and perceived QoL after a resistance exercise training program. It is suggested that individuals with PD may achieve comparable improvements to neurologically healthy adults after performing a moderate intensity resistance exercise two days per week for eight weeks (Lima et al. 2013).

Aerobic exercise has shown to be beneficial for PD individuals by reducing inflammation, suppressing oxidative stress and stabilizing calcium homeostasis (Earhart & Falvo 2013). Previously mentioned neuroplastic changes were reported to enhance corticomotor excitability following an eight week treadmill training program (Fisher et al. 2008). Studies on PD locomotion have reported improved step length, step height, cadence, step width (Bello et al. 2014), gait velocity and stride length (Fok et al. 2011). Is has further been reported that a training

strategy that induces proprioceptive feedback, may use neural circuits that differ from the basal ganglia motor pathways and thereby diminish motor symptoms such as shuffling gait (Bello et al. 2014).

Considering that a range of exercise modalities should be performed by PD individuals, dance has shown to be a very comprehensive exercise modality for individuals with PD as it entails the use of external cues, movement strategies, dynamic balance, functional movements, multitasking and cardiovascular function (Hackney & Earhart 2010).

It has been reported that flexibility, balance and functional exercises are beneficial during the early stage of PD to improve overall function and to use aerobic exercise to improve long term endurance. From this, exercise may improve resting energy expenditure, mitochondrial energy production, improved energy cost attributed to ventilation as well as improved mechanical muscle contraction efficiency and coordination (Schenkman et al. 2012).

As regular physical activity is a biological protection mechanism against degenerative processes, the importance of the importance of exercise for individuals with PD is plausible.

2.8.2 Forward gait retraining

Gait variables are one of the first decrements found due to PD. Therefore, over the past few years, PD researchers gave plenty attention to gait training i.e. over ground and especially treadmill training. In order to induce neuroplasticity through exercise, interventions should be intense and continuous.

Consistent findings from PD animal models have demonstrated that exercise rate should be beyond one's voluntary rate to show neuroprotective properties and improved motor function (Ridgel et al. 2009; Alberts et al. 2011; Rosenfeldt et al. 2015). This shows the importance of adequate intensity, specificity and repetitive activities to induce neuroplastic changes. Rosenfeldt et al. (2015) suggested differences between forced and voluntary exercise in PD to be due to different impacts on the central nervous system. That is, forced exercise may elicit increased cerebral blood flow as well as cortical and subcortical activation beyond voluntary or no exercise.

Many researchers see training on a treadmill as a form of forced exercise. By walking on a treadmill, walking speed is predetermined and maintained rather than voluntary controlled. This is useful for individuals with PD as their reduced neural activity in the cortical motor areas of the

brain may limit their ability to exercise at a self-selected high frequency and that external control of intensity may be beneficial to them (Earhart & Falvo 2013).

Herman et al. (2007) proposed a summary of possible mechanisms through which treadmill training interventions may benefit individuals with PD. Improvements in strength (Toole et al. 2005), FC and the effect of body-weight support (Toole et al. 2005; Herman et al. 2007; Bello et al. 2008) was excluded as possible mechanisms for improvement. The three possible mechanisms, as supported by literature, are pace retraining (Frenkel-Toledo et al. 2005; Herman et al. 2007), motor learning (Protas et al. 2005; Fisher et al. 2008) and corticomotor excitability (Fisher et al. 2008). Whether these mechanisms are also applicable to over ground training is not entirely clear.

It is suggested that treadmill training activates neural circuits that mediate central pattern generators to activate limb muscles repetitively and produced rhythmic movements. The treadmill itself acts as an external cueing device, or pacemaker, to force participants to walk at a more uniform and regular speed and at the same time, provides hand support and stable visual feedback (Bello et al. 2014). By walking on a treadmill, pressure load receptors on the feet, muscle spindles and Golgi tendon organs are rhythmically stimulated. Therefore, a more rhythmic GC is mediated through proprioceptive feedback and vestibular receptors which sends repetitive sensory input to the central nervous system to assist in the pacing of gait. It is through these repetitive actions that it is thought to cause neuroplasticity which may preserve neural circuits for gait performance (Herman et al. 2009). This finding is supported by Fisher et al. (2008) who reported enhanced cortical excitability after treadmill training which may suggest neuroplasticity and carry over effects four weeks after completion of the intervention. These findings show that adequate training for neural compensatory adaptations is feasible for the performance of automatic motor tasks in individuals with PD.

Treadmill training has shown major benefits in the immediate effects on individuals with PD, the long-term effects as well as their ability to sustain these improvements for an extended time after the training intervention.

Short term treadmill training appears to be superior to conventional gait training, even though these improvements may only last a short while after training. PD individuals (aged 62.1±9.1 years of which 29% were women, who had a H&Y score of 2.1±0.7 and disease duration of 2.8±2.5 years) participated in a study that entailed 4 days of training (30 minutes each) and were randomly assigned to varying sequences of progressive, speed-dependent treadmill training; distance-focused treadmill training; conventional gait therapy and no training, with testing after

each training session (Pohl et al. 2003). Gait speed, SL and percentage double support duration showed improvements (all $p < 0.01$) with only the two treadmill training interventions. Conclusions from this study should be carefully considered as the authors did not elaborate on the training tasks in the different interventions, which may have an impact on the results (Toole et al. 2005). Another short term treadmill training study used PD individuals with mild (aged 61.0±6.85 years of which 38% were women, who had a H&Y score of 2±0.3 and disease duration of 5.0±3.8 years) and moderate (aged 67.0±8.4 years of which 50% were women, who had a H&Y score of 3.0±0.0 and disease duration of 8.0±3.9 years) PD (Bello et al. 2008). Participants were assessed during over-ground walking after a 20 minute treadmill training session at a predetermined over-ground walking speed. All participants' over-ground walking speed and SL improved following the 20 minute walk on the treadmill ($p < 0.01$; Bello et al. 2008). Apart from the small sample size used in the aforementioned study, a total of 17 and 16 (Pohl et al. 2003; Bello et al. 2008, respectively), training effects might differ when interventions are performed for longer periods. Randomized controlled interventions should be performed with more similar tasks for groups, to be able to generalize results (Pohl et al. 2003; Bello et al. 2008).

An area of gait retraining for PD that received extensive attention is the use of treadmill training with and without bodyweight support.

The first report on bodyweight supported treadmill training was done on PD individuals aged 67.6±1.6 years of which 50% were women, who had a H&Y score range of 2.5 to 3 and disease duration of 4.2±0.7 years (Miyai et al. 2000). Participants trained for four weeks with 20% bodyweight support followed by four weeks of conventional training (45 minutes, 3 days per week), or vice versa, with testing before and after each intervention. The bodyweight supported training yielded greater improvements in gait speed ($p = 0.03$), SL and UPDRS motor and total scores ($p < 0.01$) compared to conventional physical therapy. Due to the small sample size (a total n=10) and lack of a control group who also performed treadmill training, it is difficult to generalize the results to the bodyweight support itself and to those with different PD disease severity or duration (Miyai et al. 2000).

Building on these shortcomings, Toole and colleagues (2005) performed a six-week (20 minutes, three days per week) treadmill training intervention to compare assisted weight bearing (25% bodyweight support) and additional weight bearing (5% added bodyweight) to normal walking. In order to determine the effects on gait and balance in individuals with PD (aged 74.58±9.7 years, disease duration not reported, of which 17% were women, who had a H&Y score of 3.96±1.07, note the different staging method reported by the authors), twenty-three participants

were randomly assigned to either of the three groups and tested while walking over ground. In response to the treadmill training, all participants showed improvement in UPDRS motor scores ($p = 0.03$), single support time ($p = 0.04$) and in SL of 4.5cm. Even though the average increase in speed of 0.3m/sec for all participants combined did not yield a significant improvement, it induced the decreased single support time while walking. The researchers reported an improvement of 9% in motor function to be meaningful. By loading participants with extra weight resulted in more improvement in motor function than during normal walking ($p = 0.04$). By increasing or decreasing bodyweight in this intervention, the researchers attempted to increase or decrease stimulation to the sensory system via the Golgi tendon organs. With their findings, it appears that this was not the cause of improvement. Improvements seen indicates that neuromuscular facilitation is possible in individuals with PD regardless of the treadmill protocol (weighted, unloaded and normal walking) used (Toole et al. 2005).

After taking positive findings by Toole and colleagues (2005) into consideration, one can assume that bodyweight support during treadmill training for individuals with PD yield comparable results and is not superior to normal treadmill training. This finding supports the possibility that neuromuscular improvements may also be found when training over ground. As body-weight supported treadmill training is expensive and not always available, the effects of treadmill training without body-weight support also received attention in literature.

A study investigated an eight week treadmill training program on thirty-one PD individuals, where speed was incrementally increased. Participants were aged 71.8±6.4 years of which 48% were women, had a H&Y score of two or three and disease duration of 4.2±0.7 years (Cakit et al. 2007). Twenty-one PD participants were randomly assigned to the treadmill training group (speed was incrementally increased up to the fastest and safest speed for the participant, then maintained for five minutes and then incrementally decreased according to tolerance) and the remaining to the control group who did not perform any training. Participants in this study did not train with bodyweight support, but showed promising improvements in walking distance and tolerated speed on the treadmill over 30±5 minutes and subjective measurements of balance and fear of falling ($p < 0.01$). Unfortunately, more specific gait parameters were not recorded (Cakit et al. 2007). This study built on previous shortcomings, i.e. small sample size and study design. Despite the positive results on treadmill training without bodyweight support, it is not to say that this training program is superior to other, similar training methods, as it might have just been the addition of physical exercise that yielded the outcomes.

The above mentioned studies indicate the positive effects of gait retraining on different aspects of the GC and especially on SL in individuals with PD by using a variety of treadmill protocols. The effect of treadmill walking on gait variability received attention in PD individuals aged 61.2±9.0 years of which 36% were women and who had a H&Y score of 2.1±0.2 – disease duration was not reported, and healthy matched controls (Frenkel-Toledo et al. 2005). Participants were assessed while walking over ground, as well as on a treadmill with similar speed to the over ground walking trials. When comparing results from over ground walking to treadmill walking at the same speed, improvements during treadmill walking were reported for walking speed ($p < 0.01$), swing time ($p = 0.03$) and SL ($p < 0.01$). Specific to this study, gait variability also improved ($p = 0.04$) to thereby produce a more stable gait pattern. It is presumed from these results that a treadmill acts as an external pace maker to improve gait rhythmicity (Frenkel-Toledo et al. 2005). Whether these improvements will still be viable after gait retraining, is not clear. Important to note with this study, is that participants held on to the handrails of the treadmill. Results can thus not be directly compared to treadmill or over ground walking without this hand support.

Building on the aforementioned shortcomings, a six-week (30 minutes, four times per week) intensive treadmill training program were performed to determine the training effect on gait rhythmicity in individuals with a PD (aged 70±6.8 years of which 33% were women) who had a disease severity that ranged between H&Y stage 1.5 and 3 and disease duration of 5.0±2.6 years (Herman et al. 2007). Treadmill walking speed was adjusted weekly by gradually increasing it to above their comfortable over ground walking speed of that week. After completion of the training program, there were no differences in balance confidence (ABC scale), swing- or stride time variability. However, gait speed and SL improved ($p = 0.01$). Herman and colleagues (2007) also investigated these variables four weeks after completion of the six weeks treadmill training program and found impressive results. Gait speed ($p = 0.03$) and SL ($p = 0.04$) even improved more than straight after the training program (Herman et al. 2007). It is however important to note that results in this studies should not be generalized, as it is not a randomized controlled study and only a few participants (n=9) were used. Concerning the results from the study by Frenkel-Toledo and colleaguegs (2005), this study does not show a carryover effect of gait variability on a treadmill to over ground walking.

The aforementioned benefits from treadmill training have shown to be superior conventional or no training. Moreover, treadmill training may induced long term positive effects that may last from one month (Herman et al. 2007) to up to four months (Miyai et al. 2000) after the intervention; however, due to study limitations, generalizability of the results is difficult.

Moreover, it is still not clear whether improvements after a treadmill gait retraining program is superior to over ground training for individuals with PD. Nevertheless, the mechanism by which treadmill training induce benefits, cannot be ignored.

Literature attributes the success of treadmill training to greater antagonist inhibition and increased agonist firing. Toole and colleagues (2005) suggested these benefits to be induced by three possible mechanisms. Firstly, literature has shown that sensori-motor training have a neuro-protective effect. Secondly, neurogenesis may occur in the basal ganglia to thereby improve signalling to the thalamus and motor cortex where commands for motor inhibition or activation are generated. Thirdly, spinal pattern generators may have been positively affected through the repetitive movement action of treadmill training to induce a more automatic movement pattern that is independent from control of the central nervous system.

The third mechanism mentioned seems to be the most apparent mechanism for improvements after treadmill training. These improvements can be attributed to the external cueing provided by this training regimen which reinforces neural circuits to contribute to gait pacing. It is suggested that a treadmill provides an external rhythm that compensates for the defective internal rhythm of the basal ganglia – this is the same mechanism that is suggested for the positive effects seen with auditory or visual cueing during training. As neural circuits may be reinforced with training on a treadmill, motor learning is also enhanced with intense, repetitive actions such as walking on a treadmill (Herman et al. 2009).

Despite these benefits, it is not clear whether gait retraining programs that has similar effects on motor learning, yield comparable results. Although treadmill training seems feasible in individuals with PD for the restoration of gait and mobility constraints, there are a few negative factors associated with treadmill training, i.e. the relatively high cost thereof, the need for relatively large facilities, the increased time commitment, the practicality and the safety risk thereof (Herman et al. 2007). Hence, over ground gait training may replace these shortcomings; however, studies on over ground gait training strategies are scarce. From this point of view, cognitive motor interventions, that made use of over ground walking, became attractive additions during training programs for individuals with PD.

A cognitive motor intervention refers to training regimens where a cognitive task and motor task is performed simultaneously (Wang et al. 2016). Two studies performed cognitive motor interventions to determine the effect thereof on gait parameters of PD individuals with H&Y stages 2 to 3. The first study used a training program with cadenced matched music for 13 weeks (30 minutes, three times a week) on PD individuals (aged 67.0±8.1 years with disease severity of

2.1±0.4 on the H&Y scale and duration of 4.5±3.3 years; of which 55% were women) to a matched control group (who did no intervention) to improve velocity ($p < 0.01$), stride time ($p = 0.02$), cadence ($p = 0.01$) and UPDRS III score ($p < 0.01$) (de Bruin et al. 2010). Building on this (without including a control group), the second study allowed seven PD individuals (aged between 50 and 90) to train for four weeks (a total of 25 minutes of walking, three times a week) by using a variety of cognitive tasks which were also tested for during training (Yogev-Seligmann et al. 2012). Gait speed and stride time variability during usual walking did not change. However, improvements in both gait speed and stride time variability were reported under all cognitive dual tasks ($p \leq 0.02$) without significant improvements in the cognitive tasks itself ($p = 0.17$; Yogev-Seligmann et al. 2012). Taken together, cognitive motor interventions seems like a good option for progressions during training as the resultant effect might aid PD individuals with dual task circumstances during daily life. Nevertheless, the lack of control group and relatively small sample size (11 and seven, respectively), makes the generalizability of the results difficult and it is not clear whether these improvements were only seen due to the addition of exercise.

It has been reported that the magnitude of variability measures between treadmill walking was comparable to over ground walking (Wuehr et al. 2013). A recent study found that treadmill compared to over ground walking in healthy individuals does not yield definite differences in spatiotemporal gait parameters, except for stride-to-stride variability measures that were less variable on a treadmill (Hollman et al. 2016). Consequently, training under conditions that alter the natural variability of the motor system, i.e. on a treadmill, may limit translation of walking performance from treadmill to over ground (Hollman et al. 2016). This was shown in stroke individuals, where two-weeks over ground walking induced greater improvements in gait speed and symmetry than treadmill walking (Combs-Miller et al. 2014). It is suggested that neural input differs between the two walking modes and manifests as altered motor output (Hollman et al. 2016). Consequently, over ground gait retraining in PD is feasible despite the scarcity thereof.

During over ground walking, conscious attention becomes much more important than during treadmill walking. Devoting conscious attention to walking is known to improve gait in individuals with PD. As walking in the reverse direction is a novel task and may require special devotion of conscious attention, it is curious whether such a training regimen may yield similar improvements in gait parameters.

From the aforementioned studies, the gaps in what needs to be done for future studies are clear, i.e. randomization of larger sample sizes; the addition of a PD control group and the use of

comparable control interventions should be considered. All these limitations are motivational reasons for future studies.

2.8.3 Backwards gait retraining

The three possible mechanisms by which treadmill gait retraining may induce benefits are pace retraining (Frenkel-Toledo et al. 2005; Herman et al. 2007), motor learning (Protas et al. 2005; Fisher et al. 2008) and corticomotor excitability (Fisher et al. 2008). From this point of view, BW (even over ground) may elicit motor learning and corticomotor excitability. Only a few intervention studies for PD included BW in their training programs. A summary of these studies are outlined in *Table 2.3.*

Protas and colleagues (2005) investigated treadmill gait training for eight weeks (three times per week) in different directions on eighteen men with PD (aged 71.3±7.4 years) who had a similar disease severity (H&Y stage 2.8±0.35) and duration (7.1±5.1 years) to the control group who didn't perform any training. The training program used in this study consisted of forward, backward (five to seven minutes each) and sideways walking (two to three minutes in each direction), at a speed greater than over ground walking speed as well as step training which included gait initiation and termination in these four directions (15-20 and 10-15 repetitions directed FW or BW and sideways each, respectively). Participants in the training group showed improvement in over ground FW gait speed and cadence while the control group also demonstrated increased cadence ($p < 0.01$). Even though only the training group showed improved stride length, differences were not significant ($p > 0.30$; Protas et al. 2005). With this study, it is important to note that participants walked at their fastest, but safest, walking speed during both training and testing. Whether the training program resulted in improved self-selected, comfortable walking speeds, was not reported. As the control group did not perform any training, the positive results might just be due to the addition of training, and not necessarily due to the specificity of the training tasks. Moreover, the effect of over ground training in the same tasks compared to treadmill training as well as the effects of the different training directions compared to one another is not known.

Table 2.3 *Table summarises previous Parkinson's gait retraining intervention studies that included backwards walking.*

	Protas et al. 2005	**Shen & Mak 2014**	**Tseng et al. 2015**
Participants	18 men Age: 72.5 ± 8.0 years H&Y: 2.9 ± 0.3 UPDRS III: 29.4 ± 10.8	51 (39.2% female) Age: 64.3 ± 8.3 years H&Y: 2.5 ± 0.5	26 (50.0% female) Age: 71.2 ± 9.2 years H&Y: 1.5 ± 0.5 UPDRS III: 20.8 ± 7.9
Groups	EXP: Treadmill walking & step initiation and termination in four directions CNT: No exercise	EXP: Multidirectional gait & balance training with augmented feedback CNT: Lower limb strength training	EXP: Forward walking training on a treadmill & at home (over-ground) CNT: None
Training program	1 hour 3x / week 8 weeks	20-60min 3-5x / week 12 weeks	1 hour 3x / week 12 weeks
Results	EXP: improved gait speed & step length Both groups: increased cadence	EXP: improved balance confidence, single leg balance time, stride length CNT: increased gait velocity Improvements maintained for up to 12 months	Improved forward and backward walking gait parameters which were maintained for up to 12 months
Conclusion	Improved dynamic balance and decreased fall risk	Multidirectional gait and balance training with augmented feedback is effective for dynamic balanace and balance confidence	Forward treadmill training may improve forward and backward gait disturbances.
Abbreviations: H&Y = Hoehn and Yahr score; UPDRS = Unified Parkinson's Disease Rating Scale; EXP = experimental group; CNT = control group			

Improving on some of the aforementioned shortcomings, Shen and Mak (2014) performed a 12 week (four weeks lab-based, four weeks home-based and another four weeks lab-based) training program that compared balance and gait training with a conventional lower-limb strength training program. Participants were randomly assigned to one of these two groups, participating in 60-minute exercise sessions three times per week. Twenty-two PD individuals (aged 63.3±8.0 years of which 41% were women) with a disease severity of 2.4±0.5 on the H&Y scale and

duration 8.1±4.3 years, were compared to twenty-three matched PD individuals. The balance and gait group performed tasks that consisted of stepping and reaching in the forward, backward and sideways directions that were progressed to cross-stepping and obstacle negotiation and further progressed to treadmill perturbation; while continuously receiving augmented feedback on their performance. The home-based exercises for this group entailed sit-to-stands as well as forward, backward and sideways walking in a straight line and around a square, to complete 20 minutes of exercise. In contrast, the control group performed conventional exercise to strengthen hip and knee muscles by using a dynamometer and a leg-press machine, progressing to functional strength exercises. The home-based exercises for the control group included walking and step climbing with ankle weights, to complete 20 minutes of exercise. After the 12 weeks training, both groups improved gait speed ($p < 0.02$); however, only the balance and gait group also improved stride length and balance confidence scores ($p = 0.03$). The most profound finding from this study was that after three months, the experimental group still showed improved movement velocity ($p = 0.03$), balance confidence, SV and SL (all $p < 0.01$), compared to baseline scores. At this time point the control group (who did conventional lower limb strength training) only showed improved SV compared to baseline testing, which were also preserved up to the twelve-month follow-up ($p < 0.01$). At the twelve-month follow-up, the experimental group still maintained the improvements seen at three months after the training program, with the exception of movement velocity ($p = 0.45$). Apart from the augmented feedback that were used in the experimental group, it seems that such balance and gait exercises may provide short-term and, more importantly, long-term mobility benefits – even if these tasks are performed over ground. With this in mind – the control group also performed some over ground walking tasks, which also yielded some positive findings. Therefore, apart from the award-based learning, it seems that over ground walking can be beneficial to PD individuals – especially if the tasks are of high intensity (Shen & Mak 2014). The variety of training components covered in this study together with the long-term carryover effects reflects the possibility of motor learning in individuals with PD. However, more research is necessary to quantify the effect of augmented feedback itself on mobility performance and balance confidence; to determine which of the training tasks in the balance and gait program are most beneficial; and what the effect of such training regimens are on other mobility parameters.

Building on this, a more recent study investigated the effect of 12 weeks (three 50 minute sessions per week, of which 30 minutes included walking on the treadmill) FW treadmill training on FW and BW gait parameters (Tseng et al. 2015). Twenty-three PD individuals (aged 71.2±9.2 years; 50% women) with similar disease severity (H&Y score 1.5±0.5) and duration (5.2±4.3

years) were included. Even after the first week, improvements were already seen in both FW and BW gait variables, such as velocity, SL, swing phase and double support phase (all $p<0.01$); however, BW variables did not improve as much as FW variables. Apart from the limitations in this study, i.e. no control group, it is curious what more investigation into BW as a training regimen might be for this population.

2.8.4 Training cues during gait retraining

Cues have been described as visual or auditory stimuli from the environment or which are generated by the individual (consciously or not) to facilitate automatic and repetitive movements (Keus et al. 2007; Nieuwboer et al. 2007). Due to the physiological mechanism of PD, these individuals have a lower activity level in certain areas of the brain, especially those areas responsible for automatic and sequential movements as with most motor activities (Lewis et al. 2000). Cueing is an example of circumventing disrupted basal ganglia circuitry to execute normal movements. Dopaminergic neurons control well-learned automatic movements, such as walking. As these neurons are disrupted with PD, automated movement strategies are affected and presents as impaired mobility (Earhart & Falvo 2013). These movements are usually regulated by internal cues. As the internal cue production that stems from matching performance outcomes with movement plans is dysfunctional due to PD, movement regulation becomes impaired. Such a disruption results in a diminished gait pattern and gait akinesia. However, PD-related impaired motor pathways in the basal ganglia can be bypassed by the use of external cues, which temporarily correct this mismatch (Peppe et al. 2007). External cues move from the thalamus to the supplementary motor cortex or from the cerebellum to the premotor cortex to allow more successful execution of mobility tasks (Earhart & Falvo 2013). Therefore, when individuals with PD perform complex motor tasks, the use of sensory stimuli influences their ability to control movement (Protas et al. 2005).

Examples of cueing include instructions to pay attention to taking big steps, walking fast, counting in rhythm while walking, swinging arms and putting heels down while walking (Fok et al. 2011). External visual cues such as stripes on a walkway or auditory cues by means of a metronome have been used to improve mobility (Peppe et al. 2007), for example, by increasing walking speed and reducing akinetic episodes (Lim et al. 2005; Earhart & Falvo 2013).

Nieuwboer et al. (2007) performed a randomized controlled trial over three weeks (the RESCUE trial) that consisted of rhythmical cueing. Despite no improvements in step frequency ($p = 0.08$) or TUG time ($p = 0.25$), improvements in gait speed ($p = 0.01$) and step length ($p < 0.01$) were found. However, these advances were diminished at the 6-week follow-up session. More

recently, Nagal and Singla (2016) found that PD individuals experience less FOG difficulty when external cues were provided.

Peppe and colleagues (2007) reported improvements in arm swing amplitude ($p < 0.05$), but not for trunk rotation after walking under four different conditions: no cue, visual cue, auditory cue, combined cues. Together with these findings, they also reported the significant impact of auditory and visual cues on arm swing compared to no cues as well as a combination of cues ($p < 0.05$). Important to note is that these benefits were obtained with an auditory beat that was at a faster rate than normal walking speed. As with previous studies, this study found visual cues to reinforced proper gait, especially SL and speed ($p < 0.01$). The effectiveness of visual cues was however not related to arm swing itself, but rather to improved movement of the pelvis and lower extremities. Moreover, results from this study indicate that the use of a combination of auditory and visual cues is rather detrimental to improvements than beneficial. The authors suggest that the use of two types of cues interfere with one another and that more improvements are seen when either of the two types of signals are used independently of the other (Peppe et al. 2007).

Frazzitta et al. (2009) compared the use of auditory and visual cues during treadmill compared to the same cues used during a traditional rehabilitation program. Participants performed 20-minute sessions daily for 4 weeks (28 sessions in total). The visual cue was a target placed on a screen that the participant had to reach. The screen synced with the subject's foot placement and cued him or her when the steps were large enough or not by prompting the individual to take a longer or shorter step. The auditory cues were synced to the visual cues at a frequency of 0.5c/s. For the traditional rehabilitation group, the visual cue consisted of lines on the floor that were spaced according to the individual's SL which were lengthened 0.05m per stride every three or four days. A musical beat at the same frequency as the treadmill group were used as an auditory cue. The performance of both groups showed improvements after the intervention. However, the group that performed the treadmill training showed significantly greater improvements than the group who followed the traditional training program. More specifically, compared to the traditional rehabilitation group, the treadmill training group showed significant differences in the FOGQ ($p = 0.01$), 6MWT distance ($p < 0.01$), gait speed ($p = 0.01$) and stride cycle time ($p = 0.03$) after the intervention.

The aforementioned studies indicate the successfulness of the use of cues in PD gait training interventions. Research suggests that external cues provide a rhythm that compensates for the impaired internal rhythm of the basal ganglia. Individuals with PD do not lose their ability, but

rather only have difficulty to generate a healthy stepping pattern. Visual cues provide visual data to fill in for the motor set deficiency and are therefore affective in activating a cerebral visual-motor pathway (Frazzitta et al. 2009). Even though the use of external cues have shown ample benefits for individuals with PD, appropriate criteria for the duration and intensity of the use thereof are yet to be developed. Important to note however, is that cues should not be used in combination, but rather be alternated to successfully improve a variety of mobility impairments.

2.8.5 Conclusion

The aforementioned subsections it is clear that gait deficits in PD can be improved. Visual inputs can however either be detrimental or helpful to individuals with PD as visual stimuli such as doorways may trigger freezing, but on the other hand, visual stimuli such as transverse lines on the floor, may improve SL (Peppe et al. 2007). As visual inputs are not always available or applicable, FW gait training itself can induce ample corrections in FW and BW gait deficits for those with PD. The effect of over ground training for individuals with PD is still an area of debate. Despite the amplified gait decrements during BW in individuals with PD, the effect of training in the reverse direction for PD individuals is scarce. Moreover, to the best of the researcher's knowledge, the comparison of forward and backwards over ground gait retraining has not yet been investigate in individuals with PD.

2.9 Problem statement

The following section initially places the study into context with a synopsis of what has been found in the literature specifically on the topic of PD gait retraining and then outlines the research question, objectives and the outcome variables.

2.9.1 Gait retraining for PD mobility in context

The most disabling features of PD include dysfunctional gait, postural transitions and turning which often relates to falls. Due to executive dysfunction in PD, dual tasking (DT) is detrimental to already impaired mobility parameters. A useful training alternative to improve aberrant transitional movements in PD might be BW. Due to the novelty and complexity of BW, neural adaptations in response to training may improve the quality of complex, multi-directional daily activities, which most often involve DT. Over ground BW gait retraining has shown to be beneficial for neurological gait rehabilitation in stroke and cerebral palsy; however, has not yet been investigated in PD. Previously, only comparisons between FW and BW in PD were done and gait retraining studies included multi-direction treadmill training. The current study is the first to investigate over ground BW compared to FW gait retraining of eight weeks in PD.

Training in complex, novel tasks may induce enhanced cortical activity for movement preparation that is beyond training in automatic tasks.

2.9.2 Research aims

The primary aim of this study was to compare an eight-week backward to a forward gait retraining programme on the mobility of individuals with mild to moderate Parkinson's disease.

A secondary aim was to assess the effect of these gait retraining programs on perceived balance confidence and quality of life.

It is hypothesized that both groups will demonstrate improvements, but that the BW group will show more improvements than the FW group.

2.9.3 Objectives

The six specific study objectives were to assess changes in the following before and after the eight-week training interventions:

1) Comparing gait parameters under single task conditions, which include gait parameters such as gait speed, different gait cycle phases, stride length and cadence as measured by the instrumented i10mWT (Chapter 3, Article 1).
2) Comparing postural transitions and turning under single task conditions, including the ability to transfer from sitting to standing, standing to sitting and turning variables as measured by the iTUG test and the i5xSTS test (Chapter 4, Article 2).
3) Gait parameters (i10mWT), postural transitions and turning (i5xSTS and iTUG) under dual task conditions (Chapter 4 & 5, Article 2 & 3).
4) Functional capacity as measured by the 6MWT (Chapter 3, Article 1).
5) Perceived balance confidence as measured by the ABC scale (Chapter 4, Article 2).
6) Disease-related quality of life measured by the PDQ-39 (Chapter 3 & 4, Article 1 & 2).

2.9.4 Variables

a) Categorical variables

- Age
- Gender
- Disease severity stage

b) Dependent variables

- Spatiotemporal gait parameters such as stride length, gait speed, cadence and gait cycle phases.
- Postural transitions during the i5xSTS test such as time to completion and sit-to-stand duration.
- Postural transitions during the iTUG test such as time to completion, stand-to-sit duration, turning duration, turning velocity and turning angle.
- Disease severity according to MDS-UPRDS parts II and III.
- Freezing and fall status (FOG-Q).
- Self-reported quality of life (PDQ-39)
- Perceived balance confidence (ABC scale).

c) Independent variables

- Eight-week forward gait retraining program
- Eight-week backward gait retraining program
- Single or dual task conditions

CHAPTER 3: ARTICLE 1

Backward compared to forward over ground gait retraining have additional benefits for gait in individuals with mild to moderate Parkinson's disease: a randomized controlled trial

3.1 Abstract

Over ground gait retraining in the reverse direction has shown to be beneficial for neurological rehabilitation, but has not yet been investigated in Parkinson's disease (PD). Backwards walking (BW) might be a useful training alternative to improve PD gait and possibly reduce fall risk during complex multi-directional daily activities. The primary aim was to compare the effect of an eight-week forward (FWG) and backwards (BWG) gait retraining program on gait parameters in PD individuals. Twenty-nine participants (aged 71.0±8.8 years; UPDRS-III 38.1±12.3; H&Y 2.7±0.5) were randomly assigned to either the control (FWG; n=14) or experimental group (BWG; n=15). Baseline measures included disease severity (UPDRS III), global cognition (MoCA) and depression (PHQ-9). Outcome measures were selected gait variables on the 10m-instrumented-walk-test (i10mWT), functional capacity (FC) with a six-minute-walk-test (6MWT) and quality of life with the Parkinson's Disease Questionnaire-39 (PDQ-39), assessed before and after the interventions. Both groups improved usual gait speed (FWG: $p=0.03$, $d=0.35$; BWG: $p<0.01$, $d=0.35$) and height-normalized gait speed (FWG: $p=0.04$, $d=0.35$; BWG: $p<0.01$, $d=0.57$) as well as FC (FWG: $d=0.82$; BWG: $d=1.06$; $p<0.01$). Additionally, the BWG demonstrated improved gait cycle (GC) time ($p=0.01$, $d=0.15$), cadence ($p<0.01$, $d=0.67$) and stride length (SL; $p=0.02$, $d=0.39$); whereas SL CoV ($p=0.04$, $d=0.83$) increased. Both interventions improved gait speed and FC sufficiently to independently navigate in the community. Also, apart from increases in SL variability, BW gait retraining was effective to improve rhythmicity and pace-domains of gait.

Key Words: Gait retraining; Parkinson's disease; Retro-walking; Gait; Rehabilitation

3.2 Introduction

Parkinson's disease (PD) is a neurodegenerative disorder with gait difficulties being the first [1] and most disabling clinical manifestation [2], even in early PD [3]. The effect of gait difficulties on the ability to perform multi-directional activities of daily living (ADL) and mobility highlights the importance of locomotive exercise alternatives that stretch beyond mere forward walking (FW). As backward stability is most affected by PD, gait retraining in the reverse direction might be of particular importance to address the variety of PD-related mobility impairments [4,5].

The four common clinical motor symptoms of PD, involving a variety of body segments, are resting tremor, postural instability, rigidity and bradykinesia which are associated with difficulty in changing direction or modulating voluntary movement [2,3]. Inadequate postural control, muscle rigidity and bradykinesia especially have an impact on gait. Moreover, impaired postural control is most prominent during backward perturbations [4,5]. Muscle rigidity causes increased co-contraction of muscles around the joints of the lower limbs, resulting in joint stiffness which limits torque. This reduction in ankle joint torque affects the primary propulsive gait mechanism [5]. Bradykinesia occurs due to delayed signal transmission from the brain to the muscles and therefore affects the planning, initiation and execution of movements [2] which reflects as a slower walking speed [6]. These symptoms collectively contribute to a distinctive walking pattern, namely decreased arm swing and short, quick, shuffling steps [7,8] that relates to mobility impairments and increased fall risk [9]. König et al. (2016) recently highlighted that mobility impairments in PD can be indicative of either selective neurophysiological damage or due to compensatory mechanisms. Consequently, locomotive impairments have a major impact on quality of life (QoL) and the collective integration of these aforementioned variables should be considered when addressing mobility in PD.

Many pharmacological treatment strategies may improve disease-related impairments; however, have limited impact on gait and postural instability [11]. Even though backwards walking (BW) has the same motor program as FW, anatomical and functional asymmetry of the foot and leg along the antero-posterior axis allows for different biomechanical constraints to be imposed during FW and BW, with BW resulting in more muscle activation of the hip and knee extensors [12]. In recent years, BW has become an attractive alternative for training and rehabilitation purposes to improve mobility in movement disorders [13–15]. For individuals with stroke, both over ground and treadmill BW training has shown to be affective to improve walking speed, stride length (SL), gait asymmetry (GA), gait cycle (GC) phases, functional capacity (FC) and

balance [16,17,18]. Similar, in children with cerebral palsy, BW treadmill training improved gait speed, step length, SL and FC [14] and the addition of over ground BW to a traditional physical therapy program improved overall postural instability [19]. These improvements may relate to increased muscle activation of the rectus femoris and tibialis anterior during BW, where muscle activity increases as the intensity, or incline of walking, increases [20].

However, BW studies specific on PD are scarce. Hackney and Earhart (2009) were the first to examine BW abilities in PD and reported FW gait deficits to be exacerbated during BW and even worse when compared to healthy, matched controls. Moreover, Peterson et al. (2014) investigated the differences between actual and imagined gait tasks in PD, i.e. simple FW with complex turning and BW. The researchers showed reduced activity in the *globus pallidus* (which regulates voluntary movement) across all three imagined tasks, reflecting the underlying gait dysfunction. Importantly, during imagined turning and BW, increased activity of the supplementary motor area (SMA) was seen. Losing dopaminergic cells in PD bring about faulty communication between subcortical and cortical structures, as well as inadequate activation of the SMA, anterior cingulate cortex and left putamen [22,23]. The SMA is believed to be important for the control of self-paced actions, storing learned motor sequences and generation of anticipatory postural adjustments [23]. Thus, compensatory neural changes might be involved during complex gait tasks like BW [24]. The aforementioned findings have triggered interest in the effect of exercise on complex mobility tasks, especially as inter-limb coordination during gait is mostly controlled by subcortical mechanisms [25]. As BW is a difficult and novel task, it can be expected that decreased coordination will be evident [4], especially in PD individuals who have coordinative deficits [26]. However, training in this task might allow motor adaptation that restores coordination and stability in both locomotive directions via alternative neural pathways.

For PD, improvements in gait speed and dynamic balance are closely related to reduced fall incidence [7]. This highlights the importance of improving walking with exercise approaches. Whether over ground gait retraining in the reverse direction can enhance motor performance in PD is yet to be determined. Backwards walking is especially important during daily activities to change direction and to avoid accidents [9]. Previously, an eight-week forward, backward and sideways gait and step intervention in PD individuals (H&Y 2-3; UPDRS-III 28.3±13.6) improved gait speed [7]; however, they did not have a exercising control group. A PD study on FW and BW treadmill training for twelve weeks showed improved gait speed, SL and GC phases after one week of training and these changes remained at four and twelve weeks after training [9].

To the researchers' knowledge, over ground forward compared to backward gait retraining in PD has not yet been investigated. If PD individuals train in a novel and complex task (like BW), it is hypothesized that BW will show additional gait improvements than FW due to superior improvements in balance, muscle activity and anticipatory postural adjustments than training an automatic task (FW); because faulty basal ganglia pathways are bypassed and intact cortical loops are utilized with BW. Therefore, the primary aim of this article was to compare an eight-week backward to a forward gait retraining programme on gait parameters of individuals with mild to moderate PD. The secondary aims included FC and QoL.

3.3 Methods

3.3.1 Study design

The single-blind randomized controlled trial, with pre- and post-testing, was approved by the *Health Research Ethics Committee* of Stellenbosch University (S16-01-004; Appendix M) before it commenced in three different locations in the Western Cape (South Africa) with staggered starts at four week intervals (April – August 2016; *Figure 3.1*). A staggered design was used to make it possible for the same evaluator to collect data at the different location and to include more individuals.

Based on data (SL, gait speed, cadence) from a preliminary study done by the same laboratory, a sample size of 40 participants was recommended by a statistician to reach a statistical power of 80% (α=0.05) and an estimated moderate effect size (d=0.60) [27,28]. Once the participants were fully cognizant of all aspects of the study, they gave verbal and written consent. After baseline testing, a concealed-simple randomization in a 1:1 ratio was done by an offsite individual who was not involved in the study recruitment, intervention or data collection procedures. Due to the study design, it was difficult to completely blind the participants to the main aim of the study. However, participants were blinded to the outcome measures as no results were disclosed or discussed during the study, nor were the true purpose revealed to the participants until after completion.

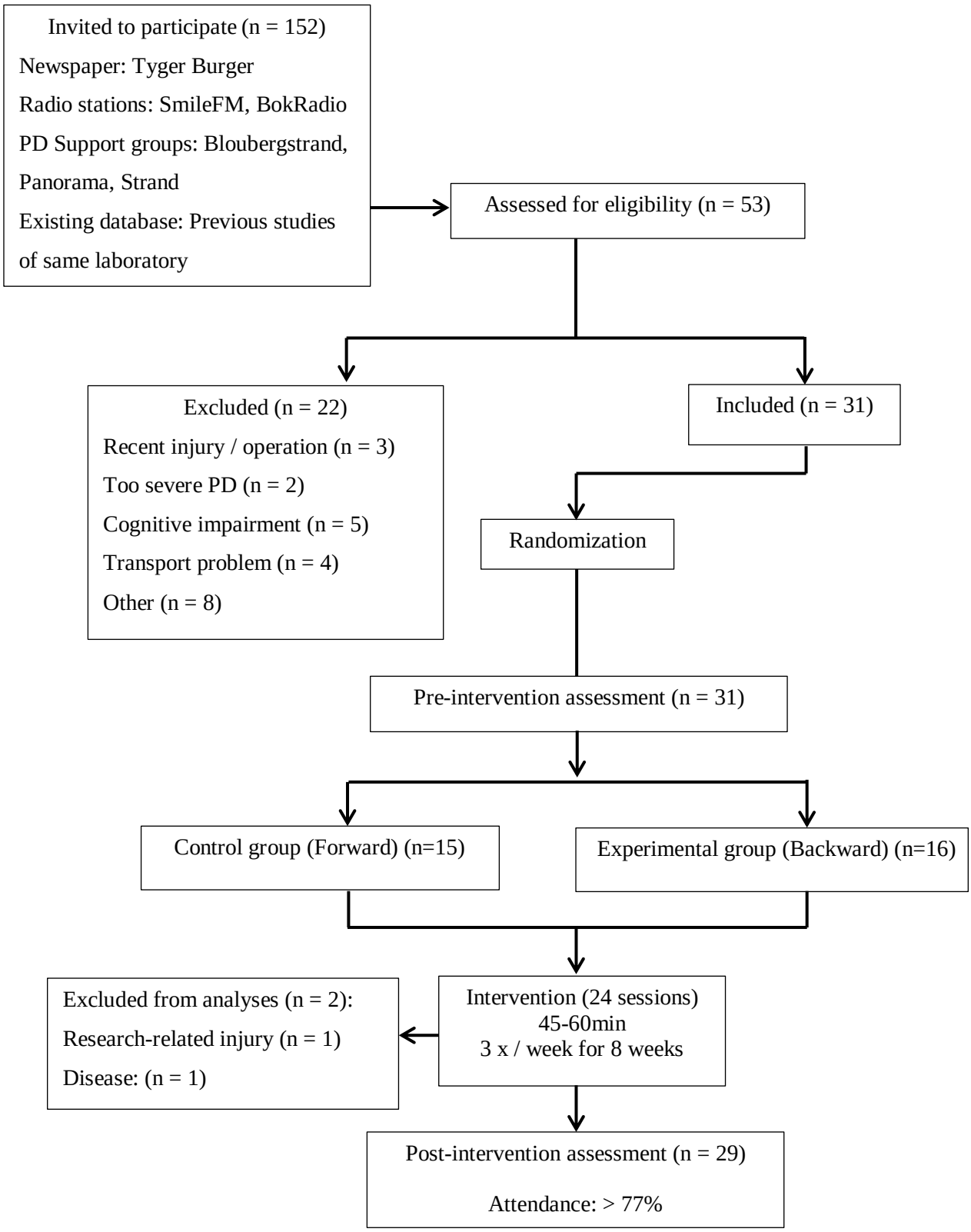


Figure 3.1 Flow diagram of study design

3.3.2 Participants

Participants aged 45-86 years with idiopathic PD, as diagnosed by a neurologist, were included. Volunteers who met the participation criteria had mild to moderate disease severity (Hoehn and

Yahr, (H&Y) stage II-III), could ambulate independently, had stable medication usage (no change over study period), were free of a medical-attention-injury for the three months prior to the intervention and did not have evidence of severe cognitive deficit (<17 on the Montreal Cognitive Assessment (MoCA) [29]). Furthermore, none of the participants had neurological, cardiovascular or musculoskeletal diseases or impairments other than PD that affected their locomotion or balance and limited their participation in the intervention. *Table 3.1* outlines descriptive characteristics of the participants.

Table 3.1 *Descriptive and clinical characteristics at baseline. Values are mean ± standard deviation (range), except where indicated otherwise*

Characteristic	**FWG n = 14**	**BWG n = 15**	**p**
Age (years)	70 ± 11 (45 - 86)	72 ± 6 (56 - 79)	0.53 ES: 0.24^{S}
Gender (Men:Women)	10:4	9:6	0.52
Height (cm)	169.6 ± 11.9 (146.0 - 199.0)	167.4 ± 8.4 (149.0 – 177.0)	0.56 ES: 0.22^{S}
BMI (kg/m^2)	27.0 ± 4.1 (20.2 - 35.6)	26.9 ± 6.0 (17.3 - 39.6)	0.98 ES: 0.02^{N}
Hoehn & Yahr stage	2.7 ± 0.5 (2 - 3)	2.7 ± 0.9 (2 - 3)	0.79 ES: 0.00^{N}
Disease duration (years)	7 ± 6 (1-20)	5 ± 3 (1-11)	0.21 ES: 0.44^{M}
UPDRS part III	40.7 ± 14.7 (17.0 - 65.0)	35.6 ± 9.5 (24.0 - 62.0)	0.27 ES: 0.43^{M}
PD-type (*f*)			
Tremor dominant (%)	4 (28.6)	7 (46.7)	
PIDG (%)	9 (64.3)	6 (40.0)	0.42
Indeterminate (%)	1 (7.1)	2 (13.3)	
Global cognition (MoCA)	24.3 ± 2.1 (19.0 - 27.0)	23.1 ± 2.8 (17.0 - 29.0)	0.26 ES: 0.50^{M}
Depression (PHQ-9)	6.7 ± 5.8 (0.0 - 24.0)	7.0 ± 5.9 (0.0 - 16.0)	0.88 ES: 0.05^{N}

Abbreviations: FWG = forward walking group; BWG = backward walking group; ES = Effect size; BMI = Body Mass Index; UPDRS = Unified Parkinson's Disease Rating Scale; *f* = number of observations; PIGD = Postural Instability and Gait Difficulty; MoCA = Montreal Cognitive Assessment; PHQ-9 = Patient Health Questionnaire – 9

3.3.3 Measurements and tests

Outcome measures were assessed before and after the eight-week exercise intervention, with the same equipment, by the primary researcher (intra-rater intraclass correlation coefficients (ICC) ranged from 0.89–0.99; p=0.58–0.15) who is a qualified clinical exercise therapist (Biokineticist). Participants were instructed to wear the same, appropriate footwear during all testing procedures. Testing ranged between 45-90 minutes per visit. Descriptive measures at

baseline included motor dysfunction (UPDRS III), disease severity stage, H&Y, global cognition (MoCA, Appendix E) and depression (PHQ-9, Appendix F). To obtain the primary outcome variables, participants completed a 10m-instrumented-walk-test (i10mWT) to collect parameters. For the secondary outcome variables, PD symptom scores were individually calculated and participants completed the six-minute-walk-test (6MWT) and Parkinson's disease questionnaire–39 (PDQ-39, Appendix H) for functional capacity and QoL, respectively.

a) Descriptive measures

Part III of the Movement Disorder Society - Unified Parkinson's Disease Rating Scale (MDS-UPDRS III) was used to describe motor dysfunction (r=0.96 [30]), to determine disease severity stage (H&Y stage [31])as well as to differentiate between tremor dominant (TD) and postural instability and gait difficulty (PIGD) individuals [32]. To screen for global cognition, the MoCA was used, which is a valid and reliable (ICC=0.79) screening instrument for all levels of cognition in PD [29,33]. To screen depressive mood status, the PHQ-9 (ICC=0.63) was used [34,35].

b) Primary outcome measures

The i10mWT was performed with Mobility Lab (APDM®, Beta version, Portland, OR, USA) that consists of six Opal inertial sensors (dimensions: 48.4mm x 36.1mm x 13.4mm). Each Opal sensor is composed of an accelerometer, gyroscope and magnetometer to track spatiotemporal parameters (2.40-2.48GHz; APDM®) [36]. After completion of the i10mWT, all selected spatiotemporal variables were exported into Excel 2010 (Microsoft®, Microsoft Corporation, USA). This inertial system is comparable to gold-standard Vicon motion analysis system (Vicon, Oxford Metrics Group, Oxford, UK) during locomotor activities in individuals with PD [37]. Desirable sensitivity, reliability and validity of gait variables (ICC: 0.74-0.87) and mobility in PD during prescribed motor tasks have been reported [36,38,39].

For the i10mWT, participants were instructed to walk at a comfortable and self-selected pace for i10m and then stop when they crossed a line on the floor without turning around. After demonstrating and checking for understanding, participants performed two trials, with no familiarization attempt, with 30-60 seconds rest in-between and the average measures were used [40]. From the i10mWT, gait speed (m/s and % stature), cadence (steps/min), SL (% stature), GC time (s) and double support phase (DS; %GC) were recorded. Furthermore, the variance of these variables (CoV=[SD÷mean]x100) as well as swing time and step duration GA were calculated as illustrated in Appendix L [41]. Variables were chosen as they relate to PD mobility impairments,

are sensitive to change and that are related to a shuffling gait pattern. Moreover, chosen variables were previously assessed in BW studies on other neurological populations.

These lower limb spatiotemporal gait parameters were chosen as literature has shown which variables are sensitive to change [36]. Also, as previous studies reported on these variables, it can be used for comparison of results from the current study. Moreover, these variables are significantly influenced by PD, as shown by their characteristic shuffling gait pattern.

c) Secondary outcome measures

Individual bradykinesia, rigidity, tremor and postural instability scores were calculated as indicated in Appendix L [42]. The 6MWT was used to assess FC, expressed as distance (m) walked. Instructions as set out by Steffen and Seney (2008) were used during the test, where participants were instructed to walk as far as possible in six minutes. Due to different sizes of the available halls, track lengths differed and participants at one of the locations walked up and down; whereas the others walked in a rectangle. It is reported that the 6MWT is a valid and reliable tool (ICC=0.96) to assess mobility impairments in PD individuals [43]. The Parkinson's Disease Questionnaire 39 (PDQ-39) was used to assess PD-related QoL. The PDQ-39 is a PD validated (r=0.72) and reliable (ICC=0.95) questionnaire to measure QoL in individuals with PD and is used to determine mild treatment effects on different PD-related domains [44]. The 8 subscales are scored from 0-100, with a higher score indicating more impact of disease on health.

3.3.4 Training intervention

The training sessions consisted of 20-30 minutes over ground gait retraining, 5-10 minutes stretching and 5-10 minutes of other activities. There were three different sequences of warm-up and cool-down activities, which were alternated throughout the training program. An expanded explanation of the intervention is provided in Appendix A. Exercise sessions were held indoors on a hard surface. Participants were instructed to perform all training sessions with the same footwear they used during the testing sessions. The weekly objectives for the intervention, which is derived from previous PD training studies, are outlined in *Table 3.2* [45–52]. Both the control (FWG) and experimental (BWG) groups followed the same objectives during the intervention. However, the FWG performed the different gait tasks in the forward direction, while the BWG performed the different gait tasks in the backward direction. The gait tasks included walking while focusing on different gait-related aspects and utilizing different types of cues. Exercises were progressed by combining gait tasks, utilizing different obstacles and by adding motor and cognitive tasks.

Table 3.2 Outline of both training programs' weekly objectives

Week	Objective
1	To become familiarized with proper posture and gait task: Foot strike and Push off
2	To become familiarized with gait task: Focusing on step length
3	Focus on overall over ground walking technique: Coordination and Gait initiation
4	To increase velocity, cadence and distance walking
5	Focus on directional change abilities
6	Concentrating on obstacle negotiation & ability to manoeuvre through tight spaces
7	Focus on locomotion as it relates to daily activities
8	Performing circuit training

3.3.5 Statistical analysis

Excel 2010 (Microsoft®) and Statistica® software (version 13, StatSoft, Inc., Tulsa, USA) for Windows were used for statistical analyses. Participant characteristics and gait performance were summarized with descriptive statistics by reporting means and standard deviations (with 95% confidence intervals (CI)) or number of observations (*f*) and percentages for qualitative data. Normality was determined with Q-Q plots and Shapiro-Wilk tests. All data was normally distributed and none were log transformed. Mixed model repeated measures Analysis of Variance (ANOVA) were used to investigate differences between groups as well as the possible effects of the intervention (pre- to post-testing). Chi-square tests for categorical data were used for group differences. Additional post hoc Fisher exact LSD calculations were applied and Cohen's effect sizes were calculated to determine practical significance, where 0.15, 0.40 and 0.75 indicates a small, medium and large effect, respectively [53]. A 5% significance level was set for all analyses.

3.4 Results

Fifty-three diagnosed PD individuals volunteered to participate, of which 31 were assessed for eligibility and 29 men and women completed the intervention and were included for analyses (*Figure 3.1*). These 29 individuals, aged between 45 and 86 years (71.0±8.8 years), had no group differences at baseline ($p>0.05$; *Table 3.1*). A summary of main- and interaction-effects of descriptive variables are outlined in Appendix O1. All except one participant was on anti-Parkinson medication. There were no differences in the time since previous medication dosage over time or between the two groups ($p>0.05$). On average, participants were tested 3.1±1.7 and 2.9±1.9 hours since taking their previous medication, at pre- and post-test, respectively.

Participants in the FWG and BWG respectively had an average attendance rate of 91.2±9.2% and 92.2±7.9%. Outcome variables over time and between groups are outlined in *Table 3.3*.

All main- and interaction-effects of outcome variables are summarized in Appendix O2. No GROUPxTIME interaction or GROUP effects were found for any of the recorded gait variables ($p>0.05$); whereas positive main TIME-effects were found for usual and normalized gait speed (both $p<0.01$), cadence ($p<0.01$), SL ($p=0.01$) and GC time ($p<0.01$). Post hoc analysis found within group improvements in both groups for gait speed before (FWG: 9.5%, $p=0.03$; BWG: 14.0%, $p<0.01$) and after (FWG: 9.5%, $p=0.03$; BWG: 14.0%, $p<0.01$) normalizing for height. Also, the BWG had within group improvements for cadence (5.6%, $p<0.01$), SL (6.9%, $p=0.02$) and GC time (5.0%, $p=0.01$). However, no between-group effects were found ($p>0.05$). For the variability measures, post hoc analysis showed only a 52% deterioration of SL variability in the BWG ($p=0.04$).

No main or within group effects were found for PIGD symptoms ($p>0.05$). A significant TIME-effect was seen for tremor scores ($p=0.02$; GROUPxTIME: $p=0.27$), where post hoc analysis showed a 12.7% improvement from pre- to post-testing for the BWG ($p=0.02$). For bradykinesia scores (TIME: $p<0.01$; GROUPxTIME $p=0.37$), both the FWG ($p<0.01$) and BWG ($p=0.01$) showed positive changes (23.6% and 12.2%, respectively) with post hoc analysis. Rigidity scores showed a TIME- ($p=0.01$) and GROUP- ($p=0.03$) effect (GROUPxTIME: $p=0.76$). Post hoc analyses for rigidity yielded higher (worse) scores at post-testing for the FWG ($p=0.05$), contributing to a between-group difference at post-testing ($p=0.04$).

Functional capacity showed a positive TIME-effect ($p<0.01$), but not a GROUPxTIME effect ($p=0.99$). After post hoc analysis, the FWG ($p=0.01$) and BWG ($p<0.01$) showed 23.4% and 33.4%, within group improvements, respectively, for 6MWT distance.

Assessment of QoL (PDQ-39 total scores) did not show a GROUPxTIME effect ($p=0.72$) or post hoc significance ($p>0.05$). Over time with participants grouped together (TIME-effect), lower scores in all eight domains were found ($p\leq0.02$; GROUPxTIME: $p>0.05$). Post hoc analysis showed that in all domains separately, only the BWG demonstrated significant within group improvement i.e. lower scores ($p\leq0.04$, *Figure 3.2*).

Table 3.3 Outcome variables. Values are mean ± standard deviation (95% CI)

Outcome variable	Pre	Post	p; ES
Gait speed (m/s)			
FWG	1.00 ± 0.25 (0.14)	1.08 ± 0.27 (0.15)	$^{3}p = 0.03$; $^{3}d = 0.32^{S}$
BWG	1.07 ± 0.28 (0.15)	1.20 ± 0.27 (0.15)	$^{4}p < 0.01$; $^{4}d = 0.49^{M}$
	$^{1}p = 0.48$; $^{1}d = 0.27^{S}$	$^{2}p = 0.23$; $^{2}d = 0.46^{M}$	
Gait speed CoV			
FWG	6.2 ± 2.8 (1.6)	5.7 ± 3.0 (1.8)	$^{3}p = 0.43$; $^{3}d = 0.18^{S}$
BWG	5.4 ± 1.8 (1.0)	6.6 ± 2.7 (1.5)	$^{4}p = 0.08$^; $^{4}d = 0.54^{M}$
	$^{1}p = 0.40$; $^{1}d = 0.35^{S}$	$^{2}p = 0.33$; $^{2}d = 0.33^{S}$	
Gait speed (%S)			
FWG	58.9 ± 14.3 (8.2)	63.8 ± 15.2 (8.8)	$^{3}p = 0.04$*; $^{3}d = 0.35^{S}$
BWG	63.7 ± 15.1 (8.4)	71.8 ± 15.5 (8.6)	$^{4}p < 0.01$*; $^{4}d = 0.55^{M}$
	$^{1}p = 0.40$; $^{1}d = 0.34^{S}$	$^{2}p = 0.16$; $^{2}d = 0.54^{M}$	
Cadence (steps/minute)			
FWG	109.0 ± 14.8 (8.5)	111.8 ± 11.2 (6.5)	$^{3}p = 0.16$; $^{3}d = 0.22^{S}$
BWG	108.9 ± 9.1 (5.1)	114.8 ± 9.1 (5.0)	$^{4}p < 0.01$*; $^{4}d = 0.67^{M}$
	$^{1}p = 0.99$; $^{1}d = 0.01^{N}$	$^{2}p = 0.48$; $^{2}d = 0.31^{S}$	
Cadence CoV			
FWG	3.8 ± 3.5 (2.0)	3.0 ± 1.6 (0.9)	$^{3}p = 0.30$; $^{3}d = 0.31^{S}$
BWG	3.3 ± 1.7 (1.0)	3.0 ± 0.9 (0.5)	$^{4}p = 0.72$; $^{4}d = 0.23^{S}$
	$^{1}p = 0.51$; $^{1}d = 0.19^{S}$	$^{2}p = 0.99$; $^{2}d = 0.00^{N}$	
Stride length (%S)			
FWG	64.7 ± 13.1 (7.5)	67.8 ± 12.9 (7.4)	$^{3}p = 0.09$^; $^{3}d = 0.34^{S}$
BWG	68.8 ± 12.1 (6.7)	73.2 ± 11.3 (6.2)	$^{4}p = 0.02$*; $^{4}d = 0.39^{S}$
	$^{1}p = 0.37$; $^{1}d = 0.34^{S}$	$^{2}p = 0.25$; $^{2}d = 0.46^{M}$	
Stride length CoV			
FWG	6.6 ± 3.6 (2.1)	6.0 ± 3.1 (1.8)	$^{3}p = 0.57$; $^{3}d = 0.18^{S}$
BWG	4.4 ± 1.4 (0.8)	6.7 ± 3.8 (2.1)	$^{4}p = 0.04$*; $^{4}d = 0.83^{L}$
	$^{1}p = 0.07$^; $^{1}d = 0.85^{L}$	$^{2}p = 0.54$; $^{2}d = 0.21^{S}$	
Gait cycle time (sec)			
FWG	1.1 ± 0.2 (0.1)	1.1 ± 0.1 (0.1)	$^{3}p = 0.07$^; $^{3}d = 0.28^{S}$
BWG	1.1 ± 0.1 (0.1)	1.1 ± 0.1 (0.1)	$^{4}p = 0.01$*; $^{4}d = 0.69^{M}$
	$^{1}p = 0.70$; $^{1}d = 0.14^{N}$	$^{2}p = 0.48$; $^{2}d = 0.43^{M}$	

Table 3.3 cont. Outcome variables. Values are mean ± standard deviation (95% CI)

Gait cycle time CoV			
FWG	4.5 ± 6.0 (3.5)	3.0 ± 1.6 (0.9)	$^{3}p = 0.22$; $^{3}d = 0.35^{S}$
BWG	3.3 ± 1.7 (1.0)	3.1 ± 1.0 (0.6)	$^{4}p = 0.87$*; $^{4}d = 0.15^{S}$
	$^{1}p = 0.32$; $^{1}d = 0.29^{S}$	$^{2}p = 0.93$; $^{2}d = 0.08^{N}$	
Double support (%GC)			
FWG	22.1 ± 4.3 (2.5)	21.5 ± 4.7 (2.7)	$^{3}p = 0.36$; $^{3}d = 0.14^{N}$
BWG	21.1 ± 5.0 (2.7)	19.8 ± 4.9 (2.7)	$^{4}p = 0.06$^; $^{4}d = 0.27^{S}$
	$^{1}p = 0.56$; $^{1}d = 0.22^{S}$	$^{2}p = 0.35$; $^{2}d = 0.37^{S}$	
Double support CoV			
FWG	10.5 ± 11.3 (6.5)	7.5 ± 4.2 (2.4)	$^{3}p = 0.24$; $^{3}d = 0.36^{S}$
BWG	6.8 ± 2.5 (1.4)	8.0 ± 5.9 (3.3)	$^{4}p = 0.63$; $^{4}d = 0.15^{S}$
	$^{1}p = 0.15$; $d = 0.48^{M}$	$^{2}p = 0.82$; $^{2}d = 0.01^{N}$	
Swing time GA			
FWG	-4.0 ± 2.1 (1.2)	-3.6 ± 3.5 (2.0)	$^{3}p = 0.71$; $^{3}d = 0.06^{N}$
BWG	-3.9 ± 3.0 (1.7)	-3.8 ± 3.6 (2.0)	$^{4}p = 0.29$; $^{4}d = 0.03^{N}$
	$^{1}p = 0.78$; $^{1}d = 0.04^{N}$	$^{2}p = 0.91$; $^{2}d = 0.06^{N}$	
Step duration GA			
FWG	-4.6 ± 3.4 (2.0)	-5.0 ± 4.7 (2.7)	$^{3}p = 0.72$; $^{3}d = 0.10^{N}$
BWG	-3.04 ± 2.7 (1.5)	-3.8 ± 3.7 (2.1)	$^{4}p = 0.42$; $^{4}d = 0.24^{S}$
	$^{1}p = 0.25$; $^{1}d = 0.53^{M}$	$^{2}p = 0.40$; $^{2}d = 0.30^{S}$	
6MWT (m)			
FWG	305 ± 114 (65.8)	372 ± 35.6 (77.0)	$^{3}p < 0.01$*; $^{3}d = 0.82^{L}$
BWG	310 ± 91 (50.1)	377.5 ± 22.9 (49.2)	$^{4}p < 0.01$*; $^{4}d = 1.06^{L}$
	$^{1}p = 0.90$; $^{1}d = 0.05^{N}$	$^{2}p = 0.89$; $^{2}d = 0.19^{S}$	
PDQ-39			
FWG	36.3 ± 16.7 (9.6)	32.8 ± 14.3 (8.3)	$^{3}p = 0.37$; $^{3}d = 0.23^{S}$
BWG	39.4 ± 26.5 (14.1)	33.9 ± 23.2 (12.8)	$^{4}p = 0.15$; $^{4}d = 0.23^{S}$
	$^{1}p = 0.70$; $^{1}d = 0.14^{N}$	$^{2}p = 0.89$; $^{2}d = 0.06^{N}$	

*p < 0.05; ^p < 0.09. [N]Negligible ES; [S]Small ES; [M]Medium ES; [L]Large ES

Abbreviations: FWG = Forward walking group; BWG = Backward walking group; ES = Effect size; CoV = Coefficient of Variance; %S = percentage stature; %GC = percentage gait cycle; GA = gait asymmetry; 6MWT = Six-minute Walk Test; PDQ-39 = Parkinson's Disease Questionnaire – 39

[1]Group difference: Baseline; [2]Group difference: Post-test; [3]FWG: Over time; [4]BWG: Over time

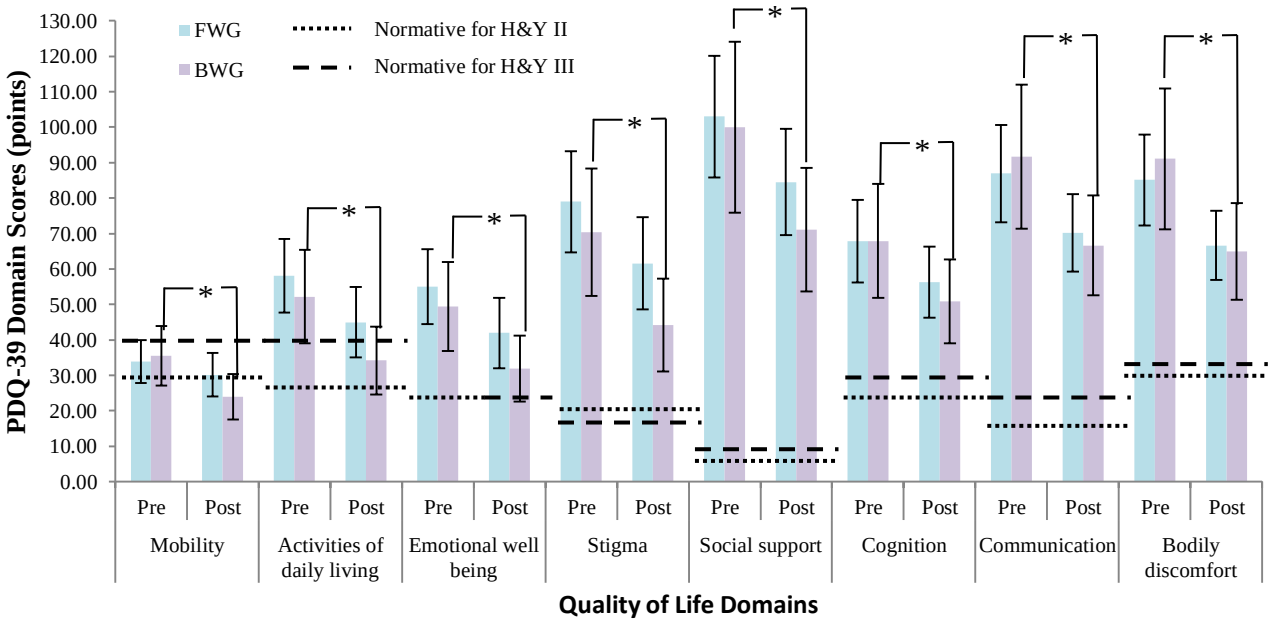


Figure 3.2 *Scores for PDQ-39 domains of both groups over time in comparison with H&Y II and III normative values* [44] *(*p≤0.04; mean and SEM)*

3.5 Discussion

This investigation aimed to compare gait parameters in a backward and forward gait retraining programme in individuals with mild to moderate PD. The main findings after the eight-week interventions were improved gait speed and FC in both the FWG and BWG. Additionally, the BWG improved their cadence, SL and GC time; whereas SL CoV increased. Even though no differences were found for PDQ-39 total scores, the BWG improved their scores in all the individual domains.

Participants in this study (aged 71.0±8.8 years) had similar baseline scores for disease duration (6.0±5.0 years) and severity (UPDRS III: 38.1±12.3; H&Y 2.7±0.5) as well as other descriptive variables, except for a large practical difference in SL CoV (p>0.05). This can be related to the FWG having worse rigidity scores than the BWG at baseline, as shown by a moderate trend, but large practical significant difference. It is well known that rigidity restricts movement [5], specifically by impairing hip extension [5]. Participants were classified as being overweight (BMI 26.9±5.1kg/m^2) and having mildly impaired global cognition (MoCA 23.1±2.8).

3.5.1 Gait speed

The 10mWT is an indicator of functional mobility and is used to assess gait speed. Gait speed showed an average of 9.6% improvement in both groups. Adequate gait speed is vital for

physical performance, independence and survival in the elderly. For instance, gait speeds greater than 1.0 m/s are associated with better survival rates and less than 0.6 m/s with mortality, hospitalization and institutionalization [54,55]. Both groups in the current study surpassed these thresholds in the i10mWT. From a functional point of view, a gait speed of 1.2m/s is necessary to negotiate typical crosswalks [56], which was found in the BWG after the intervention.

The BWG increased their gait speed (1.2±0.3m/s) up to what has been reported for comfortable walking speed in healthy elderly individuals aged 60-69 years (1.2±1.5m/s) [57], 70-74 years (1.2±0.2m/s) [56] and 70-79 years (1.2±1.4m/s) [57]. Compared to a gait speed of 0.9±0.3m/s that has recently been reported for PD individuals (H&Y 2.0±1.0; disease duration 5.9±3.7 years) of similar age to the current study [3,58,59], participants of both groups walked faster before and after the intervention. Ellis et al. (2015) reported that gait speed slows down on average by 0.08 m/s over a two-year period in PD. Both groups in the current investigation showed a minimal clinically important improvement (between 0.02–0.06m/s [61] in gait speed during 10mWT.

In PD, gait speeds less than 0.88 m/s has been associated with engaging less in community walking [62]. Factors that affect gait speed have been well-reported. Non-modifiable factors relating to gait speed in PD include age (gait speed decreases with ageing), gender (women walk slower than men) and height (taller individuals walk faster) [3,56]. Considering modifiable factors, gait speed is reduced with obesity, fatigue, low physical activity levels, depression, disease severity (only partially modifiable), impaired muscle strength, fear of falling and fall risk, impaired QoL as well as lower mobility, emotional and cognitive states [3]. The normalization of gait speed to height usually dissipates gender differences, hence gait speed is more a function of stature than gender [56]. Consequently, gait speed was normalized to stature in the current study. Nevertheless, stature did not influence the outcome of walking speed. Apart from the fact that participants in this study were overweight, they still met the proposed minimum gait speed that is necessary to move about in the community. With regards to muscle strength, previous work reported greater quadriceps activation in healthy individuals during BW [63]. Regarding physical activity levels, there were no between group differences ($p=0.32$); hence physical activity status did not contribute to the outcomes. Although muscle strength was not directly assessed in the current study, it is possible that BW influenced it and contributed to gait speed improvements in the BWG. For the purposes of this study, fatigue, fear of falling and fall risk were not directly assessed.

Gait speed generally improves with treadmill training [64,65]. Four weeks of FW treadmill training has shown superior improvements in gait speed and SL compared to physiotherapeutic gait training [66] or no training [67] in PD. There seem to be some discrepancies between research, while some researchers have found an improvement in gait speed after four to six weeks of gait training [67,68], others did not [69]. Considering the inconsistency of these findings and limitations in the respective studies, it is not clear whether treadmill training is superior to over ground training for PD individuals. Findings from the current study illustrates that over ground gait retraining in PD can indeed be effective to improve PD gait speed. Other multi-directional gait retraining in PD showed superior results for gait speed compared to a non-exercising control group [7] as well as to a lower-limb strength training program [51]. Tseng et al. (2015) compared FW treadmill gait retraining on FW and BW gait parameters in PD and reported improved gait speed for both walking directions after twelve weeks of training. Therefore FW or BW training or testing direction share the same motor program, and appear to be transferable, as well as supporting the findings of the current study. Cadence and SL are the key components of gait speed, which is a major determinant of mobility in PD individuals [61].

3.5.2 Cadence

Cadence is controlled by connections to the brainstem [8]. Consequently, cadence generally remains intact in PD [70,71]. Both the FWG and BWG had step frequencies that were higher than for similarly aged PD individuals [58], but was in line with what has been reported for healthy individuals aged 70-74 years with a cadence of 108-114steps/min [56,72]. However, results differ from healthy individuals aged 60-69 and 70-79 years, with a cadence of 120±12steps/min and 120±6steps/min, respectively [57].

It was suggested that with visually-cued gait training, visual cues bypass the basal ganglia-SMA loops to activate cortical structures, utilizing loops that are accessed with conscious voluntary controlled movements [73]. As BW is a novel and complex task and requires conscious, voluntary control, it is possible that BW training bypasses dopa-sensitive cortico basal ganglia circuits and in doing so, improve the dopa-resistive parameter cadence.

Significant improvements for cadence in the BWG relates back to improved gait speed and SL. The FWG also improved in gait speed, but this was accompanied with smaller non-significant increases in cadence and SL. Increased muscle stiffness may influence cadence as it limits progression of the swing limb, thereby restricting SL. Usually, if an increased in gait speed is present without increased SL, a compensatory increase in cadence is observed [73]. Rigidity

scores for the FWG increased over time, possibly influencing SL and cadence, but overall gait speed still improved. Cadence generally does not improve with treadmill training [64], as was seen in the FWG. In addition, a similar change over time in cadence, as for FWG, has been found in other motor rehabilitation programs for PD of similar age, disease duration and UPDRS III scores [74].

The BWG had a larger magnitude change in cadence. Previously, multi-directional gait retraining in PD showed superior results for cadence compared to a non-exercising control group [7]. Changes in cadence may suggest that the stimulus of the BW intervention might have activated connections to the brainstem as well to thereby induce a more automatic forward gait pattern [8].

3.5.3 Stride length

The inability to generate a normal SL is a fundamental problem underlying gait hypokinesia in PD as it results the characteristic PD shuffling gait pattern, which can be a large contributor to falls [72]. Stride length is usually higher in men than in women [56]. Consequently, normalized SL values were used for comparisons.

The cortical motor area is involved in the selection of SL, whereas the basal ganglia maintains the selected SL. Thus, basal ganglia disruption of SL reduces gait speed [8]. Individuals with PD generally have a shorter SL compared to healthy elderly due to bradykinesia, muscle stiffness, decreased muscle activity and reduced kinaesthetic awareness [73]. Differences in SL is shown by previously reported results for SL of 77.4±11.9% for healthy individuals aged 70-74 years [56,59] compared to 61.4±12.3% for PD individuals that were similarly aged to the current study [58, 59, 74-76]. Even at baseline, participants of the current study had longer SL, which substantially increased in response to the intervention, than what was previously reported in PD. Even though SL values approached that of healthy individuals, it seems that the presence of PD-related symptoms still restricts normal age-matched SL.

A recent review on treadmill training studies concluded from ten studies that SL generally does not improve with treadmill training [64]. Recently, FW treadmill gait retraining for FW and BW gait parameters in PD were compared, showing improved SL for both walking directions after twelve weeks of training [9]. Findings from the current study illustrates that over ground BW can also be an effective strategy to improve impaired SL in PD.

In response to the intervention, both the FWG and BWG improved bradykinesia scores. This may be related to improved SL in the BWG, but as the FWG had worse rigidity scores at post-

testing, the increased muscle stiffness might have limited progression of the swing limb, consequently restricting their SL [73]. Moreover, previous literature suggest that BW increases muscle activity in healthy individuals [20]. If this also holds true for the BWG, increased muscle activity might have contributed to their improved SL [73].

Parkinson's disease individuals have altered phasing of distal lower limb muscle activation during the GC. Keeping in mind that BW induces high levels of extensor muscle activity [20] and that BW training previously improved lower limb muscle strength [12,15], BW in the current study, compared to FW, may have contributed to superior lower leg extensor muscle strength, which is vital for generating long and brisk strides during FW [68].

Better upright posture, i.e. less flexed or forward bent posture, may improve stride length. Video motion analysis was not used in the current study, but perhaps the BW resulted in a more upright posture due to better kinaesthetic feedback, as well as the BW direction tends to shifts one's trunk back. Future studies should investigate this.

Attention is seen as an internal cue and highly influences gait control. Both internal and external cues target dopaminergic gait dysfunction, i.e. SL; whereas stride to stride fluctuations in gait is only influenced by external cues [77]. In the same way that external cues place attention on stride length to induce improvements, conscious attention used with BW may induce improvements through the same mechanism, i.e. bypassing the basal ganglia to consequently not make use of faulty internal regulation [73]. More specifically, the locomotor pattern is more easily maintained due to enhanced peripheral kinaesthetic feedback [73,78]. Considering that the internal regulation of SL is the fundamental deficit in PD gait, SL improvements may carry over to improved cadence and gait speed in the BWG [78].

3.5.4 Gait cycle time (or Stride time)

Results from the current study are in line with previously reported GC times of healthy individuals, i.e. values of 1.1±0.1sec for healthy individuals compared to 1.2±0.2sec in PD [79–81]. Interestingly, it appears that average GC time only has secondary importance to gait disturbances in PD as it is not related to any measures of disease severity or duration and is not responsive to levodopa [82]. As GC time was improved in the BWG, BW seems effective in addressing aspects of gait that is not addressed by dopaminergic therapies.

Some PD studies found the GC time to be increased, compared to healthy individuals [74,75] and that there is no difference in GC time between over ground and treadmill walking in healthy

and PD individuals [80]. Results from the current study are in line with these previously reported GC times of healthy individuals.

Apart from improved gait speed in both groups, the additional improvement of cadence and SL of the BWG may relate to their improved GC time, suggesting improved ability to transfer their weight from one limb to the other and shifting their centre of mass forward [74].

3.5.5 Gait variability

Gait difficulty in PD is expressed as stride-to-stride variability [78,81,83,84]. Basal ganglia dysfunction contributes to impaired bilateral coordination, which leads to increased gait variability. Variability in GC and SL fluctuations generally reflect neural control stepping under unconscious control [85], indicating disturbances in walking rhythmicity [10]. In the current study, only SL variability increased and this was seen in the BWG only. Stride length variability could be an indication of fall risk, marker of freezing of gait and decreased ability to produce a steady gait rhythm [78,83,84,86]. Although research to support the relationship between parameters and the effect of pathology on each parameter are scarce [10], there are a few possible reasons for findings in the current study.

Firstly, SL variability is at its highest during slow and fast gait speeds, but during a comfortable walking pace, an individual walks at the most mechanically and metabolically cost effective pace and SL variability is at its lowest [80,87]. Keeping in mind that participants walked faster than what has been reported for comfortable walking speed in PD individuals of similar age and disease severity level while the BWG also presented with SL variability, it might indicate that the BWG rather walked at a fast pace, in contrast to comfortable gait speed that was instructed. From these findings, a linear relationship between SL variability and gait speed is suggested, possibly reflecting one arm of the characteristic U-shape relationship between these two variables [87].

Secondly, a possibly explanation is that the faster gait speeds resulted in postural instability, which may have contributed to SL variability as the participant tries to account for these balance instabilities.

Thirdly, apart from decreased rhythmicity, SL variability also suggested reduced automaticity. In motor control, high and low variability respectively suggests elevated and minimal attentional involvement, depending on the automaticity of the process. In healthy adults, rhythmical stepping requires minimal attention and therefore changes in SL variability are often not found during circumstances that require high levels of attention [88]. Individuals with PD however

struggle to perform learned motor skills automatically [89,90], for example a shorter SL [90]. It is possible that the increased gait speed seen in the BWG created a disruption in postural control. Consequently, they had to pay more attention during walking and their limited attention capacity during walking is reflected as variability in SL.

Fourthly, due to the limited strides during the i10mWT, it is possibly that variability parameters included in the results are not a true reflection of the underlying pathology. Compared to only ten strides that are needed to assess average gait parameters, at least 50 strides are required to accurately measure variability measures [56,91].

Finally, pathology can also have an influence on variability [10]. Depending on the specific parameter, a detrimental gait pattern can be observer with either higher or lower variability. This can be explained by increased variability indicating an unstable gait pattern (i.e. stride time); whereas decreased variability could suggest more severe rigidity or less flexibility and adaptability in movement (i.e. step width and stance time) [10].

To summarize, even in healthy individuals, gait variability is not reduced during preferred walking speed [80,87], suggesting variability during walking is essential for effective motor performance and it is possible that an optimal level of variability may exist depending on the individual, context and task [10,92,93]. Seeing that even the expression of SL variability as an absolute or relative value show differences [87], direct comparison between different populations, or even within different subtypes of PD, might be difficult.

3.5.6 Functional capacity

Functional capacity has an impact on QoL and is a good indicator of mobility and predictor of fear of falling [94]. The positive impact of gait retraining for PD individuals is supported by the 28.4% improved 6MWT distance for the FWG and BWG, even without reaching the minimum detectable change of 82m [38].

Distances reported for similarly aged healthy individuals were 439-498m (Jones, & Rikli 2002), which is much further than participants of the current study, reflecting the impact of PD motor impairments on FC. Previous studies reported 395m (aged 64.0±10.0 years; H&Y 2.1±0.7; disease duration 2.4±1.8 years) and 461m (aged 74.7 years; H&Y 2.7; disease duration 6.2 years) in PD individuals in their sixties [96,97] and seventies [98], respectively. A more recent study reported a mean distance of 546m in PD individuals (aged 65.0±6.9 years; H&Y score 2.4±0.5; disease duration 7.2±5.0) [70] which is more than the previously mentioned studies. Discrepancies found in distances walked in six minutes may be explained by different courses

used as well as different disease duration and motor symptom scores. Taken together, participants in the current study matched gait speed of healthy and other PD individuals over a short distance (i10mWT), but could not maintain this pace over six minutes, as they could not walk further than healthy individuals.

Frazzitta et al. (2009) reported improved 6MWT distance with treadmill training of up to 351±125m, which is slightly less than participants in the current study; however their baseline results were substantially lower, leaving more room for improvement. The current intervention, which entailed over ground gait retraining, seems effective for improving cardiovascular function which generally affects gait and mobility in PD [100]. Falvo and Earhart (2009) stated that training for PD individuals that target improving balance and reducing falling risk factors may increase the distances walked in the 6MWT (i.e. walking capacity). Considering this together with the gait parameters that improved, it seems that BW and FW training improved mobility in PD participants by improving balance and functional capacity.

3.5.7 Quality of life

Health-related QoL is indicative of functioning and well-being. When the total QoL score was divided into the different domains, only the BWG showed significant improvements in all eight domains. Considering reported values for H&Y stage 2 PD individuals [44], only the mobility domain was below these values in both groups during pre- and post-testing. Over time, only the BWG improved the ADL and emotional well-being domains to below these values. Looking at the norms for H&Y stage 3 PD individuals [44], the same trend was seen in all the domains, apart from the ADL domain, where the FWG also improved their scores, even though not significantly, to below these values. Moreover, a minimal detectable change [102] was found in only the BWG for all but the mobility and cognition domains.

Participants of the current study scored substantially lower than previously reported total scores of 48.1±13.4 [103] and 50.2±33.6 [104]. Comparing results of the individual PDQ-39 domains of these two studies, participants in the current study had higher (worse) scores for social support, cognition, communication and bodily discomfort domains, but lower (better) scores for the mobility and emotional well-being domains [103,104]. For the ADL-domain, the FWG had lower scores [103,104] and the BWG had a lower score compared to Tamás et al. (2014), but a higher score compared to Sabari et al. (2015). The exact opposite was found for the stigma-domain. Even though disease duration and H&Y stage were similar [104], discrepancies in findings may be due to age differences [103].

According to Hagell et al. (2007), PDQ-39 has been found to be bias towards disease duration and severity; however, in the current study there was not a significant difference in disease duration between the two groups, and the BWG improved in disease severity significantly over time. These findings suggest that gait retraining may have an impact on some, but not all quality of life domains and that these domains might have a relationship to improved gait parameters.

3.5.8 Limitations and future studies

Only spatiotemporal parameters were measured, which has been recently reported as not being sensitive enough to disease severity. Future studies should also include kinetic parameters, which may be more beneficial for biomechanical interpretation of the results.

Data were collected over a short distance – 10m. Even though gait parameters can be accurately measured over short distances and a small amount of strides, variability of gait parameters especially will be more reliable when data is collected from more than 50 strides [56] or according to Owings et al. (2003) at least 200 strides. This may also contribute to findings from the current study as participants in both groups walked on average 22 strides during the i10mWT.

Due to time constraints, no retention tests were done to monitor the long-term effects of the intervention. Also, this study did not include a non-exercising control group and conclusions are therefore only based on FW compared to BW in the sample included. However, previous literature suggests that doing some exercise is more beneficial than doing no exercise [69,105–107]. As there currently is no consensus on the optimal rehabilitation modality for PD, comparison studies are of importance for future research.

Time after medication intake can also influence gait variability. It has been suggested that the PD gait pattern is most stable within 165 minutes after levodopa intake [3]. Both groups had equal time since their previous dosage (approximately 177 minutes). However, testing within a shorter timeframe may influence gait parameters differently, especially the dopa-sensitive pace-domain outcomes, i.e. gait speed, SL, DS time variability and swing velocity.

Participants of the current study walked at self-selected, not maximal speeds. These results should thus not be generalized to performance at fast-as-possible or slower speeds.

Results from this study might not be representative of individuals with more severe PD. Also, the small sample size makes it difficult to divide and make conclusions of participants in PD subtypes and for gender differences. Hence, a larger sample size may be effective to determine if

the conclusions found in the current study have different effects on PD subtypes. Future studies should endeavour in solving financial, time, logistical and geographical factors that limited the inclusion of more participants.

3.5.9 Conclusion

This investigation expands on previous studies by adding an exercising control group [7,9,69] and by making use of similar training components in the two interventions except for the differences in movement direction, which makes generalizability of the results to a specific intervention easier, compared to different training types previously used [51]. Findings from the current study contribute to the use of over ground, particularly BW, gait retraining, to improve gait parameters in PD, which has not yet been investigated previously. Motor dysfunction in PD is related to dopamine loss in the basal ganglia, and as the disease progresses, the sub-thalamic nucleus is also affected. Consequently, the preparation, execution and maintenance of movement during automatic tasks are disrupted, resulting in decreased adaptability in functional mobility responses [99]. It has however been reported that dopamine medication predominantly influences spatial more than temporal gait parameters in PD [85]. Consequently, alternative strategies, like BW, to improve temporal parameters (i.e. cadence and stride time) should be kept in mind during rehabilitation approaches. Furthermore, considering that a gait speed of 0.88m/s is required to adequately navigate in the community [3], increasing and maintaining gait speed in PD is essential and was achieved by the current intervention together with improved FC that relates to independence and improved mobility. In conclusion, results from the current study shows that despite SL increases that can be interpreted differently, eight-weeks over ground BW gait retraining can be effective to improve rhythmicity and pace-domains of gait, suggesting improved automaticity, mobility and balance.

3.5.10 Acknowledgements

The researchers thank the participants for their time and effort to complete the intervention, Miss EM Atterbury for assisting with the exercise sessions as well as Prof M Kidd for assisting with the statistical analyses. This publication was supported by Grant Number TTK13070920812 from the National Research Foundation (NRF, South Africa). Its contents are solely the responsibility of the authors, and do not necessarily represent the official views of the NRF. The authors also acknowledge the Department of Sport Science (Stellenbosch University) for support.

3.6 References

[1] L.M. Shulman, A.L. Gruber-Baldini, K.E. Anderson, C.G. Vaughan, S.G. Reich, P.S. Fishman, W.J. Weiner, The evolution of disability in Parkinson disease, Mov. Disord. 23 (2008) 790–796. doi:10.1002/mds.21879.

[2] A. Nagal, R.K. Singla, Parkinson â€™s Disease : Diagnosis , Therapeutics & Management Parkinson â€™s Disease : Diagnosis , Therapeutics & Management, WebmedCentral Pharm. Sci. 3 (2016) WMC003670. http://www.webmedcentral.com/article_view/3670 Subject.

[3] N. Paker, D. Bugdayci, G. Goksenoglu, D.T. Demircioğlu, N. Kesiktas, N. Ince, Gait speed and related factors in Parkinson's disease., J. Phys. Ther. Sci. 27 (2015) 3675–9. doi:10.1589/jpts.27.3675.

[4] M.E. Hackney, G.M. Earhart, Effects of dance on movement control in Parkinson's disease: A comparison of Argentine tango and American ballroom, J. Rehabil. Med. 41 (2009) 475–481. doi:10.2340/16501977-0362.

[5] D.S. Peterson, F.B. Horak, Neural Control of Walking in People with Parkinsonism, Physiology. 31 (2016) 95–107. doi:10.1152/physiol.00034.2015.

[6] J. Vandenbossche, N. Deroost, E. Soetens, J. Spildooren, S. Vercruysse, A. Nieuwboer, E. Kerckhofs, Freezing of gait in Parkinson disease is associated with impaired conflict resolution., Neurorehabil. Neural Repair. 25 (2011) 765–773. doi:10.1177/1545968311403493.

[7] E.J. Protas, K. Mitchell, A. Williams, H. Qureshy, K. Caroline, E.C. Lai, Gait and step training to reduce falls in Parkinson's disease., NeuroRehabilitation. 20 (2005) 183–190.

[8] M. Danoudis, R. Iansek, Gait in Huntington¿s disease and the stride length-cadence relationship., BMC Neurol. 14 (2014) 161. doi:10.1186/s12883-014-0161-8.

[9] I.-J. Tseng, R.-Y. Yuan, C. Jeng, Treadmill Training Improves Forward and Backward Gait in Early Parkinson Disease, Am. J. Phys. Med. Rehabil. (2015) 1. doi:10.1097/PHM.0000000000000273.

[10] N. König, N.B. Singh, C.R. Baumann, W.R. Taylor, Can Gait Signatures Provide Quantitative Measures for Aiding Clinical Decision-Making? A Systematic Meta-Analysis of Gait Variability Behavior in Patients with Parkinson's Disease., Front. Hum. Neurosci. 10 (2016) 319. doi:10.3389/fnhum.2016.00319.

[11] B.R. Bloem, N.M. de Vries, G. Ebersbach, Nonpharmacological treatments for patients with Parkinson's disease, Mov. Disord. 30 (2015) 1504–1520. doi:10.1002/mds.26363.

[12] Y. Laufer, Effect of age on characteristics of forward and backward gait at preferred and accelerated walking speed., J. Gerontol. A. Biol. Sci. Med. Sci. 60 (2005) 627–632. doi:10.1093/gerona/60.5.627.

[13] Y.-R. Yang, R.-Y. Wang, Y.-C. Chen, M.-J. Kao, Dual-task exercise improves walking ability in chronic stroke: a randomized controlled trial., Arch. Phys. Med. Rehabil. 88 (2007) 1236–1240. doi:10.1016/j.apmr.2007.06.762.

[14] S.-G. Kim, Y.U. Ryu, H.D. Je, J.H. Jeong, H.-D. Kim, Backward walking treadmill therapy can improve walking ability in children with spastic cerebral palsy: a pilot study, Int. J. Rehabil. Res. 36 (2013) 246–252. doi:10.1097/MRR.0b013e32835dd620.

[15] X. Zhang, Y. Zhang, X. Gao, J. Wu, X. Jiao, J. Zhao, X. Lv, Investigating the role of backward walking therapy in alleviating plantar pressure of patients with diabetic peripheral neuropathy, Arch. Phys. Med. Rehabil. 95 (2014) 832–839. doi:10.1016/j.apmr.2014.01.003.

[16] J.Y. Taipei, M.W. Hospital, L. Yen, C. Hsin, R. Medical, Gait outcomes after additional backward walking training in patients with stroke : a randomized controlled trial, (2005) 264–273.

[17] V.G. DePaul, L.R. Wishart, J. Richardson, T.D. Lee, L. Thabane, Varied overground walking-task practice versus body-weight-supported treadmill training in ambulatory adults within one year of stroke: a randomized controlled trial protocol, BMC Neurol. 11 (2011) 129. doi:10.1186/1471-2377-11-129.

[18] K. Kim, S. Lee, K. Lee, Effects of Progressive Body Weight Support Treadmill Forward and Backward Walking Training on Stroke Patients ' Affected Side Lower Extremity ' s Walking Ability, (2014).

[19] H.M.Y. El-Basatiny, A.A. Abdel-Aziem, Effect of backward walking training on postural balance in children with hemiparetic cerebral palsy: a randomized controlled study., Clin. Rehabil. 29 (2015) 457–67. doi:10.1177/0269215514547654.

[20] M. Lee, J. Kim, J. Son, Y. Kim, Kinematic and kinetic analysis during forward and backward walking., Gait Posture. 38 (2013) 674–8. doi:10.1016/j.gaitpost.2013.02.014.

[21] D.S. Peterson, K.A. Pickett, R.P. Duncan, J.S. Perlmutter, G.M. Earhart, Brain activity during complex imagined gait tasks in Parkinson disease, Clin. Neurophysiol. 125 (2014) 995–1005. doi:10.1016/j.clinph.2013.10.008.

[22] J. Jankovic, Parkinson's disease: clinical features and diagnosis, J. Neurol. Neurosurg. Psychiatry. 79 (2008) 368–376. doi:10.1136/jnnp.2007.131045.

[23] J.V. Jacobs, J.S. Lou, J.A. Kraakevik, F.B. Horak, The supplementary motor area contributes to the timing of the anticipatory postural adjustment during step initiation in participants with and without Parkinson's disease, Neuroscience. 164 (2009) 877–885. doi:10.1016/j.neuroscience.2009.08.002.

[24] D.S. Peterson, K.A. Pickett, R.P. Duncan, J.S. Perlmutter, G.M. Earhart, Brain activity during complex imagined gait tasks in Parkinson disease, Clin. Neurophysiol. 125 (2014) 995–1005. doi:10.1016/j.clinph.2013.10.008.

[25] P. Meyns, G. Molenaers, K. Desloovere, J. Duysens, Interlimb coordination during forward walking is largely preserved in backward walking in children with cerebral palsy, Clin. Neurophysiol. 125 (2014) 552–561. doi:10.1016/j.clinph.2013.08.022.

[26] S. Hulbert, A. Ashburn, L. Robert, G. Verheyden, A narrative review of turning deficits in people with Parkinson's disease, Disabil. Rehabil. 37 (2015) 1382–1389. doi:10.3109/09638288.2014.961661.

[27] T. Gregory, K. Welman, Somatosensory training for postural control in independent-living individuals with Parkinson's disease, Dr. Diss. Stellenbosch Univ. (2015).

[28] E.M. Atterbury, Home-based balance training for dynamic balance in independent- living individuals with Parkinson's disease, Dr. Diss. Stellenbosch Univ. (2016).

[29] S. Hoops, S. Nazem, A.D. Siderowf, J.E. Duda, S.X. Xie, M.B. Stern, D. Weintraub, Validity of the MoCA and MMSE in the detection of MCI and dementia in Parkinson disease, Neurology. 73 (2009) 1738–1745. doi:10.1212/WNL.0b013e3181c34b47.

[30] C.G. Goetz, S. Fahn, P. Martinez-Martin, W. Poewe, C. Sampaio, G.T. Stebbins, M.B. Stern, B.C. Tilley, R. Dodel, B. Dubois, R. Holloway, J. Jankovic, J. Kulisevsky, A.E. Lang, A. Lees, S. Leurgans, P.A. LeWitt, D. Nyenhuis, C.W. Olanow, O. Rascol, A. Schrag, J.A. Teresi, J.J. Van Hilten, N. LaPelle, Movement disorder society-sponsored revision of the unified Parkinson's disease rating scale (MDS-UPDRS): Process, format, and clinimetric testing plan, Mov. Disord. 22 (2007) 41–47. doi:10.1002/mds.21198.

[31] M.M. Hoehn, M.D. Yahr, Parkinsonism : onset , progression , and mortality, 17 (1967). doi:10.1212/WNL.17.5.427.

[32] G.T. Stebbins, C.G. Goetz, D.J. Burn, J. Jankovic, T.K. Khoo, B.C. Tilley, How to identify tremor dominant and postural instability/gait difficulty groups with the movement disorder society unified Parkinson's disease rating scale: Comparison with the unified Parkinson's disease rating scale, Mov. Disord. 28 (2013) 668–670. doi:10.1002/mds.25383.

[33] J.C. Dalrymple-Alford, M.R. MacAskill, C.T. Nakas, L. Livingston, C. Graham, G.P. Crucian, T.R. Melzer, J. Kirwan, R. Keenan, S. Wells, R.J. Porter, R. Watts, T.J. Anderson, The MoCA: Well-suited screen for cognitive impairment in Parkinson disease, Neurology. 75 (2010) 1717–1725. doi:10.1212/WNL.0b013e3181fc29c9.

[34] K. Kroenke, R.L. Spitzer, J.B.W. Williams, The PHQ-9: Validity of a brief depression severity measure, J. Gen. Intern. Med. 16 (2001) 606–613. doi:10.1046/j.1525-1497.2001.016009606.x.

[35] M.H.N. Chagas, V. Tumas, G.R. Rodrigues, J.P. Machado-De-Sousa, A.S. Filho, J.E.C. Hallak, J.A.S. Crippa, Validation and internal consistency of patient health questionnaire-9 for major depression in parkinson's disease, Age Ageing. 42 (2013) 645–649. doi:10.1093/ageing/aft065.

[36] M. Mancini, F.B. Horak, Potential of APDM Mobility Lab for the monitoring of the progression of Parkinson's disease, Expert Rev. Med. Devices. 4440 (2016) 17434440.2016.1153421. doi:10.1586/17434440.2016.1153421.

[37] M.A. Simoes, Feasibility of Wearable Sensors to Determine Gait Parameters, Dep. Mech. Eng. Master of (2011) 108. doi:10.1007/s13398-014-0173-7.2.

[38] T. Steffen, M. Seney, Test-retest reliability and minimal detectable change on balance and ambulation tests, the 36-item short-form health survey, and the unified Parkinson disease rating scale in people with parkinsonism., Phys. Ther. 88 (2008) 733–746. doi:10.2522/ptj.20070214.

[39] L.I.I.K. Lim, E.E.H. Van Wegen, C.J.T. De Goede, D. Jones, L. Rochester, V. Hetherington, A. Nieuwboer, A.M. Willems, G. Kwakkel, Measuring gait and gait-related activities in Parkinson's patients own home environment: A reliability, responsiveness and feasibility study, Park. Relat. Disord. 11 (2005) 19–24. doi:10.1016/j.parkreldis.2004.06.003.

[40] M.E. Morris, R. Iansek, T. a Matyas, J.J. Summers, Stride length regulation in Parkinson â€™s disease Normalization strategies and underlying mechanisms, Brain. 119 (1996) 551–568. doi:10.1093/brain/119.2.551.

[41] M. Plotnik, N. Giladi, Y. Balash, C. Peretz, J.M. Hausdorff, Is freezing of gait in Parkinson's disease related to asymmetric motor function?, Ann. Neurol. 57 (2005) 656–663. doi:10.1002/ana.20452.

[42] M. Ganesan, T.N. Sathyaprabha, P.K. Pal, A. Gupta, Partial Body Weight-Supported Treadmill Training in Patients with Parkinson Disease: Impact on Gait and Clinical Manifestation, Arch. Phys. Med. Rehabil. 96 (2015) 1557–1565. doi:10.1016/j.apmr.2015.05.007.

[43] R.P. Duncan, A.L. Leddy, G.M. Earhart, Five Times Sit to Stand Test Performance in Parkinson Disease, Arch. Phys. Med. Rehabil. 92 (2011) 1431–1436. doi:10.1016/j.apmr.2011.04.008.Five.

[44] C. Jenkinson, R. Fitzpatrick, V. Peto, R. Greenhall, N. Hyman, The Parkinson's disease questionnaire (PDQ-39): Development and validation of a Parkinson's disease summary index score, Age Ageing. 26 (1997) 353–357. doi:10.1093/ageing/26.5.353.

[45] G. Brichetto, E. Pelosin, R. Marchese, G. Abbruzzese, Evaluation of physical therapy in parkinsonian patients with freezing of gait : a pilot study, Clin. Rehabil. 20 (2006) 31–35. doi:10.1191/0269215506cr913oa.

[46] a Nieuwboer, G. Kwakkel, L. Rochester, D. Jones, E. van Wegen, a M. Willems, F. Chavret, V. Hetherington, K. Baker, I. Lim, Cueing training in the home improves gait-related mobility in Parkinson's disease: the RESCUE trial., J. Neurol. Neurosurg. Psychiatry. 78 (2007) 134–140. doi:10.1136/jnnp.200X.097923.

[47] S.G. Brauer, M.H. Woollacott, R. Lamont, S. Clewett, J. O'Sullivan, P. Silburn, G.D. Mellick, M.E. Morris, Single and dual task gait training in people with Parkinson's disease: a protocol for a randomised controlled trial., BMC Neurol. 11 (2011) 90. doi:10.1186/1471-2377-11-90.

[48] C. Peters, M. Currin, S. Tyson, A. Rogers, S. Healy, S. McPhail, S.G. Brauer, K. Heathcote, T. Comans, A randomized controlled trial of an enhanced interdisciplinary community based group program for people with Parkinson's disease: study rationale and protocol., Neurol. Int. 4 (2012) e3. doi:10.4081/ni.2012.e3.

[49] D.S. Peterson, M. Plotnik, J.M. Hausdorff, G.M. Earhart, Evidence for a relationship between bilateral coordination during complex gait tasks and freezing of gait in Parkinson's disease, Park. Relat. Disord. 18 (2012) 1022–1026. doi:10.1016/j.parkreldis.2012.05.019.

[50] S. Keus, M. Munneke, M. Graziano, J. Paltamaa, E. Pelosin, J. Domingos, B. Ramaswamy, J. Prins, C. Struiksma, L. Rochester, A. Nieuwboer, B. Bloem, European Physiotherapy Guideline for Parkinson ' s Disease Developed with twenty European professional associations, KNGF/ParkinsonNet, the Netherlands. 1 (2014) 32.

[51] X. Shen, M.K.Y. Mak, Balance and Gait Training With Augmented Feedback Improves Balance Confidence in People With Parkinson's Disease: A Randomized Controlled Trial., Neurorehabil. Neural Repair. 28 (2014) 524–535. doi:10.1177/1545968313517752.

[52] R.G. Cohen, V.S. Gurfinkel, E. Kwak, A.C. Warden, F.B. Horak, Lighten Up: Specific Postural Instructions Affect Axial Rigidity and Step Initiation in Patients With Parkinson's Disease, Neurorehabil. Neural Repair. 29 (2015) 878–888. doi:10.1177/1545968315570323.

[53] W. Thalheimer, S. Cook, How to calculate effect sizes from published research: A simplified methodology, Work. Res. (2002) 1–9. doi:10.1113/jphysiol.2004.078915.

[54] S. Studenski, S. Perera, D. Wallace, J. Chandler, P. Duncan, E. Rooney, M. Fox, J. Guralnik, Physical performance measures in the clinical setting., J. Am. Geriatr. Soc. 51 (2003) 314–22.

[55] M. Houles, G. Abellan Kan, Y. Rolland, S. Andrieu, P. Anthony, J. Bauer, O. Beauchet, M. Bonnefoy, M. Cesari, L.M. Donini, S. Gillette-Guyonnet, M. Inzitari, I. Jurk, F. Nourhashemi, E. Offord-Cavin, G. Onder, P. Ritz, A. Salva, M. Visser, B. Vellas, Gait speed at usual pace as a predictor of adverse outcomes in community-dwelling older people [French] La vitesse de marche comme critere de fragilite chez la personne agee vivant au domicile, Cah. l'Annee Gerontol. 2 (2010) 13–23. doi:10.1007/s12603-009-0246-z.

[56] J.H. Hollman, E.M. McDade, R.C. Petersen, Normative spatiotemporal gait parameters in older adults, Gait Posture. 34 (2011) 111–118. doi:10.1016/j.gaitpost.2011.03.024.

[57] T. Oberg, A. Karsznia, K. Oberg, Basic gait parameters: reference data for normal subjects, 10-79 years of age., J. Rehabil. Res. Dev. 30 (1993) 210–23. doi:10.1080/19397030902947041.

[58] Y.R. Yang, Y.Y. Lee, S.J. Cheng, P.Y. Lin, R.Y. Wang, Relationships between gait and dynamic balance in early Parkinson's disease, Gait Posture. 27 (2008) 611–615. doi:10.1016/j.gaitpost.2007.08.003.

[59] N. Toosizadeh, J. Mohler, H. Lei, S. Parvaneh, S. Sherman, B. Najafi, Motor performance assessment in Parkinson's disease: Association between objective in-clinic, objective in-home, and subjective/semi-objective measures, PLoS One. 10 (2015) 1–15. doi:10.1371/journal.pone.0124763.

[60] T.D. Ellis, J.T. Cavanaugh, G.M. Earhart, M.P. Ford, K.B. Foreman, A. Thackeray, M.S. Thiese, L.E. Dibble, Identifying clinical measures that most accurately reflect the progression of disability in Parkinson disease, Park. Relat. Disord. (2015). doi:10.1016/j.parkreldis.2016.02.006.

[61] C.J. Hass, M. Bishop, M. Moscovich, E.L. Stegemöller, J. Skinner, I. a Malaty, A.W. Shukla, N. McFarland, M.S. Okun, Defining the clinically meaningful change in gait speed in Parkinson's disease, J. Neurol. Phys. Ther. 38 (2014) in press. doi:10.1097/NPT.0000000000000055.

[62] R.G. Elbers, E.E.H. Van Wegen, J. Verhoef, G. Kwakkel, Is gait speed a valid measure to predict community ambulation in patients with Parkinson's disease?, J. Rehabil. Med. 45 (2013) 370–375. doi:10.2340/16501977-1123.

[63] T. Woo, H. Tseng, B. Liu, Evaluating the Difference of Physiological Load between Forward and Backward Exercise, (n.d.) 464–472.

[64] J. Mehrholz, J. Kugler, A. Storch, M. Pohl, K. Hirsch, B. Elsner, Treadmill training for patients with Parkinson's disease. An abridged version of a Cochrane Review., Eur. J. Phys. Rehabil. Med. (2016).

[65] O. Bello, J.A. Sanchez, M. Fernandez-del-olmo, Treadmill Walking in Parkinson ' s Disease Patients : Adaptation and Generalization Effect, 23 (2008) 1243–1249. doi:10.1002/mds.22069.

[66] M. Pohl, G. Rockstroh, S. Rückriem, G. Mrass, J. Mehrholz, Immediate Effects of Speed-Dependent Treadmill Training on Gait Parameters in Early Parkinson's Disease, Arch. Phys. Med. Rehabil. 84 (2003) 1760–1766. doi:10.1016/S0003-9993(03)00433-7.

[67] I. Miyai, Y. Fujimoto, Y. Ueda, H. Yamamoto, S. Nozaki, T. Saito, J. Kang, Treadmill training with body weight support: Its effect on Parkinson's disease, Arch. Phys. Med. Rehabil. 81 (2000) 849–852. doi:10.1053/apmr.2000.4439.

[68] T. Toole, C.G. Maitland, E. Warren, M.F. Hubmann, L. Panton, The effects of loading and unloading treadmill walking on balance, gait, fall risk, and daily function in Parkinsonism., NeuroRehabilitation. 20 (2005) 307–322.

[69] T. Herman, N. Giladi, L. Gruendlinger, J.M. Hausdorff, Six Weeks of Intensive Treadmill Training Improves Gait and Quality of Life in Patients With Parkinson's Disease: A Pilot Study, Arch. Phys. Med. Rehabil. 88 (2007) 1154–1158. doi:10.1016/j.apmr.2007.05.015.

[70] C.G. Canning, L. Ada, J.J. Johnson, S. McWhirter, Walking capacity in mild to moderate Parkinson's disease, Arch. Phys. Med. Rehabil. 87 (2006) 371–375. doi:10.1016/j.apmr.2005.11.021.

[71] Q.J. Almeida, C.A. Lebold, Freezing of gait in Parkinson's disease: A perceptual cause for a motor impairment?, J. Neurol. Neurosurg. Psychiatry. 81 (2010) 513–518. doi:10.1136/jnnp.2008.160580.

[72] M.S. Bryant, D.H. Rintala, J.G. Hou, A.L. Charness, A.L. Fernandez, R.L. Collins, J. Baker, E.C. Lai, E.J. Protas, Gait variability in Parkinson's disease: influence of walking speed and dopaminergic treatment, Neurol. Res. 33 (2011) 959–964. doi:10.1179/1743132811Y.0000000044.

[73] G.N. Lewis, W.D. Byblow, S.E. Walt, Stride length regulation in Parkinson's disease: the use of extrinsic, visual cues., Brain. 123 (Pt 1 (2000) 2077–2090. doi:10.1093/brain/123.10.2077.

[74] A. Peppe, C. Chiavalon, P. Pasqualetti, D. Crovato, C. Caltagirone, Does gait analysis quantify motor rehabilitation efficacy in Parkinson's disease patients?, Gait Posture. 26 (2007) 452–462. doi:10.1016/j.gaitpost.2006.11.207.

[75] R.D.M. Roiz, E.W.A. Cacho, M.M. Pazinatto, J.G. Reis, A. Cliquet, E.M. a Barasnevicius-Quagliato, Gait analysis comparing Parkinson's disease with healthy elderly subjects., Arq. Neuropsiquiatr. 68 (2010) 81–86. doi:10.1590/S0004-282X2010000100018.

[76] W. Nanhoe-Mahabier, A.H. Snijders, A. Delval, V. Weerdesteyn, J. Duysens, S. Overeem, B.R. Bloem, Walking patterns in Parkinson's disease with and without freezing of gait, Neuroscience. 182 (2011) 217–224. doi:10.1016/j.neuroscience.2011.02.061.

[77] L. Rochester, K. Baker, V. Hetherington, D. Jones, A.M. Willems, G. Kwakkel, E. Van Wegen, I. Lim, A. Nieuwboer, Evidence for motor learning in Parkinson's disease: Acquisition, automaticity and retention of cued gait performance after training with external rhythmical cues, Brain Res. 1319 (2010) 103–111. doi:10.1016/j.brainres.2010.01.001.

[78] J.P. Azulay, S. Mesure, O. Blin, Influence of visual cues on gait in Parkinson's disease: Contribution to attention or sensory dependence?, J. Neurol. Sci. 248 (2006) 192–195. doi:10.1016/j.jns.2006.05.008.

[79] A. Salarian, H. Russmann, F.J.G. Vingerhoets, C. Dehollain, Y. Blanc, P.R. Burkhard, K. Aminian, Gait assessment in Parkinson's disease: Toward an ambulatory system for long-term monitoring, IEEE Trans. Biomed. Eng. 51 (2004) 1434–1443. doi:10.1109/TBME.2004.827933.

[80] S. Frenkel-Toledo, N. Giladi, C. Peretz, T. Herman, L. Gruendlinger, J.M. Hausdorff, Treadmill walking as an external pacemaker to improve gait rhythm and stability in Parkinson's disease, Mov. Disord. 20 (2005) 1109–1114. doi:10.1002/mds.20507.

[81] J.M. Hausdorff, J. Lowenthal, T. Herman, L. Gruendlinger, C. Peretz, N. Giladi, Rhythmic auditory stimulation modulates gait variability in Parkinson's disease, Eur. J. Neurosci. 26 (2007) 2369–2375. doi:10.1111/j.1460-9568.2007.05810.x.

[82] J.D. Schaafsma, N. Giladi, Y. Balash, A.L. Bartels, T. Gurevich, J.M. Hausdorff, Gait dynamics in Parkinson's disease: Relationship to Parkinsonian features, falls and response to levodopa, J. Neurol. Sci. 212 (2003) 47–53. doi:10.1016/S0022-510X(03)00104-7.

[83] J.H. Hollman, M.K. Watkins, A.C. Imhoff, C.E. Braun, K.A. Akervik, D.K. Ness, A comparison of variability in spatiotemporal gait parameters between treadmill and overground walking conditions, Gait Posture. 43 (2016) 204–209. doi:10.1016/j.gaitpost.2015.09.024.

[84] M. Wuehr, R. Schniepp, C. Pradhan, J. Ilmberger, M. Strupp, T. Brandt, K. Jahn, Differential effects of absent visual feedback control on gait variability during different locomotion speeds, Exp. Brain Res. 224 (2013) 287–294. doi:10.1007/s00221-012-3310-6.

[85] S. Lord, K. Baker, A. Nieuwboer, D. Burn, L. Rochester, Gait variability in Parkinson's disease: An indicator of non-dopaminergic contributors to gait dysfunction?, J. Neurol. 258 (2011) 566–572. doi:10.1007/s00415-010-5789-8.

[86] J.M. Hausdorff, Gait dynamics, fractals and falls: Finding meaning in the stride-to-stride fluctuations of human walking, Hum. Mov. Sci. 26 (2007) 555–589. doi:10.1016/j.humov.2007.05.003.

[87] F. Danion, E. Varraine, M. Bonnard, J. Pailhous, Stride variability in human gait: The effect of stride frequency and stride length, Gait Posture. 18 (2003) 69–77. doi:10.1016/S0966-6362(03)00030-4.

[88] O. Beauchet, V. Dubost, F.R. Hermann, R.W. Kressig, Stride-to-stride variability while backward counting among healthy young adults Olivier, J. Neuroeng. Rehabil. 2 (2005) 1–8. doi:10.1186/1743- 0003-2-26

[89] A. Nieuwboer, L. Rochester, L. M??ncks, S.P. Swinnen, Motor learning in Parkinson's disease: limitations and potential for rehabilitation, Park. Relat. Disord. 15 (2009) 53–58. doi:10.1016/S1353-8020(09)70781-3.

[90] T. Wu, M. Hallett, P. Chan, Motor automaticity in Parkinson's disease, Neurobiol. Dis. 82 (2015) 226–234. doi:10.1016/j.nbd.2015.06.014.

[91] N. König, W.R. Taylor, G. Armbrecht, R. Dietzel, N.B. Singh, Identification of functional parameters for the classification of older female fallers and prediction of "first-time" fallers., J. R. Soc. Interface. 11 (2014) 20140353. doi:10.1098/rsif.2014.0353.

[92] E. Todorov, M.I. Jordan, Supp Optimal feedback control as a theory of motor coordination, Nat. Neurosci. 5 (2002) 1226–1235. doi:10.1038/nn963.

[93] N. Stergiou, R.T. Harbourne, J.T. Cavanaugh, Optimal Movement Variability: A New Theoretical Perspective for Neurologic Physical Therapy, J. Neurol. Phys. Ther. 30 (2006) 120–129. doi:10.1097/01.NPT.0000281949.48193.d9.

[94] C. Curtze, J.G. Nutt, P. Carlson-Kuhta, M. Mancini, F.B. Horak, Objective Gait and Balance Impairments Relate to Balance Confidence and Perceived Mobility in People With Parkinson's Disease., Phys. Ther. (2016) ptj.20150662-. doi:10.2522/ptj.20150662.

[95] R. Jones, J., Rikli, Fitness of older adults, J. Act. Aging. (2002) 24–30. doi:10.1016/j.neuroimage.2011.02.054.

[96] C.E. Garber, J.H. Friedman, Effects of fatigue on physical activity and function in patients with Parkinson's disease, Neurology. 60 (2003) 1119–1124. doi:10.1212/01.WNL.0000055868.06222.AB.

[97] M.J. Falvo, G.M. Earhart, Six-Minute Walk Distance in Persons With Parkinson Disease: A Hierarchical Regression Model, Arch. Phys. Med. Rehabil. 90 (2009) 1004–1008. doi:10.1016/j.apmr.2008.12.018.

[98] M. Schenkman, T.M. Cutson, M. Kuchibhatla, J. Chandler, C. Pieper, Reliability of impairment and physical performance measures for persons with Parkinson's disease., Phys. Ther. 77 (1997) 19–27.

[99] G. Frazzitta, R. Maestri, D. Uccellini, G. Bertotti, P. Abelli, Rehabilitation treatment of gait in patients with Parkinson's disease with freezing: A comparison between two physical therapy protocols using visual and auditory cues with or without treadmill training, Mov. Disord. 24 (2009) 1139–1143. doi:10.1002/mds.22491.

[100] T. Herman, N. Inbar-Borovsky, M. Brozgol, N. Giladi, J.M. Hausdorff, The Dynamic Gait Index in healthy older adults: The role of stair climbing, fear of falling and gender, Gait Posture. 29 (2009) 237–241. doi:10.1016/j.gaitpost.2008.08.013.

[101] M.J. Falvo, G.M. Earhart, Reference equation for 6-minute walk in individuals with Parkinson disease, J. Rehabil. Res. Dev. 46 (2009) 1121. doi:10.1682/JRRD.2009.04.0046.

[102] V. Peto, C. Jenkinson, R.A.Y. Fitzpatrick, Determining minimally important differences for the PDQ-39 Parkinson's disease questionnaire, Age Ageing. 30 (2001) 299–302. doi:10.1093/ageing/30.4.299.

[103] G. Tamás, L. Gulácsi, D. Bereczki, P. Baji, A. Takáts, V. Brodszky, M. Péntek, Quality of life and costs in Parkinson's disease: A cross sectional study in Hungary, PLoS One. 9 (2014) 1–7. doi:10.1371/journal.pone.0107704.

[104] J.S. Sabari, D. Ortiz, K. Pallatto, J. Yagerman, S. Glazman, I. Bodis-Wollner, Activity engagement and health quality of life in people with Parkinson's disease., Disabil. Rehabil. 37 (2015) 1411–5. doi:10.3109/09638288.2014.972588.

[105] B.D. Cakit, M. Saracoglu, H. Genc, H.R. Erdem, L. Inan, The effects of incremental speed-dependent treadmill training on postural instability and fear of falling in Parkinson's disease., Clin. Rehabil. 21 (2007) 698–705. doi:10.1177/0269215507077269.

[106] N. de Bruin, J.B. Doan, G. Turnbull, O. Suchowersky, S. Bonfield, B. Hu, L.A. Brown, Walking with music is a safe and viable tool for gait training in Parkinson's disease: the effect of a 13-week feasibility study on single and dual task walking., Parkinsons. Dis. 2010 (2010) 483530. doi:10.4061/2010/483530.

[107] G. Yogev-Seligmann, N. Giladi, M. Brozgol, J.M. Hausdorff, A training program to improve gait while dual tasking in patients with Parkinson's disease: A pilot study, Arch. Phys. Med. Rehabil. 93 (2012) 176–181. doi:10.1016/j.apmr.2011.06.005.

CHAPTER 4: ARTICLE 2

Forward compared to backward over ground gait retraining for improved postural transitions and turning in mild to moderate Parkinson's disease: a randomized controlled trial

4.1 Abstract

Introduction: Transitional movements are an essential part of locomotion and functional independence, but are severely affected by Parkinson's disease (PD) and often cause freezing blocks, falls and consequently reduced quality of life. The effect of training in the reverse direction has not yet been investigated in PD. The primary aim was to compare the effect of forward (FWG) and backward (BWG) gait retraining sessions on postural transitions and turning in individuals with PD. **Methods**: Twenty-nine PD individuals (71.0±8.8 years, 34.5% women, disease duration of 6.0±5.0 years, Unified Parkinson's Disease Questionnaire (UPDRS) III 38.1±12.3, H&Y stage 2.7±0.5), in the Western Cape, were randomly assigned (concealed, simple randomization, 1:1 ratio) to either the forward (FWG, n=14) or backward (BWG, n=15) walking group. Participants were blinded to the primary outcome measures, which were sit-to-stand (STS) and stand-to-sit transitions as well as turning variables, as measured with inertial sensors during a Five times STS (i5xSTS) and Timed-up-and-go (iTUG) test under both single task (ST) and dual task (DT) conditions (to determine %DT cost) before and after an eight-week intervention (3x/week). Secondary outcome measures included disease severity (UPDRS III), the PDQ-39 (Parkinson's Disease Questionnaire-39) Mobility domain, balance confidence via the Activity-specific Balance Confidence (ABC) scale and freezing status with the Freezing of gait Questionnaire (FOG-Q). **Results:** In response to the intervention, both groups improved ST turning velocity (FWG: p=0.04, *d*=0.28; BWG: p=0.05, *d*=0.28) and MDS-UPDRS III scores (FWG: p=0.02, *d*=0.45; BWG: p=0.03, *d*=0.62). Additionally, the FWG improved their i5xSTSST duration (p<0.01; *d*=0.52), iTUG duration (iTUGST: p<0.01, *d*=0.71 & iTUG^{DT}: p=0.02, *d*=0.54) and turning angle (ST: p=0.02, *d*=0.52 & DT: p=0.01, *d*=0.62); whereas the BWG also improved PDQ-39 Mobility sub-scores (p=0.01; *d*=0.41). **Conclusion:** Forward, over ground gait retraining can be a beneficial non-pharmacological and non-surgical method to improve transitional movements in mild to moderate PD.

Key Words: Locomotion, Parkinson's disease, Retro-walking, Postural transitions, Turning

4.2 Introduction

Functional activities, that are crucial for independence, consist of a range of behaviors including gross functional mobility. Gross functional mobility, also referred to as transitional movements, is associated with a change in body position (i.e. the center-of-mass moves outside the base-of-support) as well as physical conditions influencing the ability to change position. Ambulation or gait is a transitional movement which is often investigated in Parkinson's disease (PD); however turning and postural transitions are just as important for daily goal-directed locomotion [1]. For example, moving from sitting in a car to standing next to the car or to safely execute a turn in the shop aisle. The regulation and control of movement is highly affected in PD [2] especially maintaining equilibrium during transitional movements [3].

Turning is a multifaceted activity that requires high levels of coordination from the central nervous system [4]. Due to motor planning deficits, turning dysfunction is a common mobility impairment in PD with over 50% of PD individuals finding it as one of the most difficult tasks to perform [2,5]. Consequently, from a neural point of view, when PD individuals switch from one motor program to another (i.e. walking to turning), there is insufficient time to change from postural preparatory to executive movement phases [2,5]. Compared to healthy matched individuals turning 180°, mild to severe PD individuals present with increased turning duration and number of steps used as well as decreased turning velocity, a smaller base of support, a smaller turning angle, decreased inter-segmental coordination and smaller angular velocities of trunk rotation [2,4–7]. These turning deficits can be found in all stages of the disease; however, as the disease progresses, these deficits become worse.

During a turn, the center of gravity must be controlled over a changing base of support. The inability to effectively maintain stability while turning is especially hazardous during daily activities which often entails quick and unpredictable turns [4]. The adaptations during turning decrease neuromuscular demands [8] and the smaller steps might preserve stability during a turn. However, the amount of movements that need to be initiated, controlled and terminated are increased. Movement initiation can be considered the ultimate asymmetrical walking task and is worsened by bradykinesia [9,10]. This consequently increases the possibility of freezing, which often contributes to falls [2,5,8,11,12].

In effect, falls while turning is much more common than during straight walking and eight-times more likely to cause a hip fracture [5]. Furthermore, turning deficits may not always improve with anti-Parkinson medications or may even decrease turning duration in severe PD [13]. This

highlights the importance of exercise strategies that may induce adequate levels of neuromuscular control to successfully execute a turn.

Impaired stability and postural control, together with other factors that affect mobility, such as lower-extremity strength and proprioception, are also linked to sit-to-stand performance [1]. Strength of the lower limb muscles plays an important role in the control of upright stability in individuals with PD to thereby reduce fall frequency [14]. Moreover, impaired force production in PD is suggested to be related to under-activation of the cortical motor centres and the inability to fully recruit motor neurons of the working muscle [12]. A training modality complex enough to induce more activation in the cortical motor centres, may infer mobility improvements beyond what is found with less complex training tasks to thereby reduce fall risk and improve quality of life (QoL).

Backwards walking (BW) is a task that is simple in description and action, but complex in its execution and potential benefits. It is presumed that backwards training may improve balance, postural transitions, anticipatory postural adjustments and freezing of gait [15,16]. Even though research on benefits of BW in PD are scarce, studies on healthy individuals reported that BW training can minimize knee joint loads [17], increase muscle strength with greater quadriceps activation, improve endurance [17], increase energy consumption [18] and enhance stance phase stability [17]. Regarding BW for neurological conditions, a number of studies have been done on stroke by Taipei et al. (2005), DePaul et al. (2011), Kim et al. (2014) and Michaelsen et al. (2014) as well as on cerebral palsy by Kim et al. (2013), Lee et al. (2013) and El-basatiny (2015).

Although individuals with early PD have desirable walking parameters, their transitional movements could be impaired [4,8]. This is reflected by altered magnitude, but not timing, of strategies used which is scaled to the required demands [8]. Again, it is reported that anti-Parkinson medication have no effect on [8] or even may even worsen balance deficits in PD [13], especially during the more advanced disease stages. Therefore, the current study endeavors to determine the effect of backwards gait retraining on transitional movements such as sit-to-stand, stand-to-sit and turning in PD. Due to dopamine denervation in the basal ganglia, movement automaticity is reduced in PD. From this, Wu & Hallet (2005) highlighted that PD individuals use more attention to execute movements and have difficulty with dual tasking (DT). By becoming accustomed with BW, motor unit recruitment efficiency could be improved to possibly reduce aberrant movement patterns beyond what is found with traditional, less complex, training modalities [24] and possibly improve automaticity under DT conditions.

McIsaac et al. (2015) defined DT as 'the simultaneous execution of two tasks which have distinct goals and often involve motor and/or cognitive task sets'. Situations where one performs a secondary task while walking is evident in many activities of daily living such as walking and talking, crossing a street while watching traffic or carrying groceries. As PD individuals have impaired executive function, they have difficulty in switching attention from one stimulus to another [26], which negatively affects their mobility. Changes in mobility, while DT, are often related to the way in which an individual allocates available attentional resources to each task. Some research suggests that maintaining stability under DT conditions is not necessarily a priority (Ulmann & Williams, 2011). Falls are also common while DT during walking or balancing as PD individuals divide attention to perform all the tasks equally well [27,28]. Koch et al. (2009) found that stepping backward is an avoidance behaviour towards aversive situations and therefore increased cognitive control relative to stepping forward, suggesting that BW may improve executive functioning.

The primary aim of this study was to compare an eight-week backward to a forward gait retraining program on postural transitions and turning of PD individuals under single (ST) and dual task (DT) conditions. Secondary aims included motor symptom severity, perception of mobility disability, balance confidence and freezing of gait status. It was hypothesized that the BW group (BWG) will show additional improvements compared to the FW group (FWG).

4.3 Methods

4.3.1 Study design

This randomized controlled trial took place three different locations in the Western Cape (South Africa) in a staggered multiple baseline design. Fifty-three interested PD individuals were contacted to participate of which 31 met the participation criteria (*Table 4.1*). Participants provided written informed consent before participating as approved by the University's Health Research Ethics Committee (S16-01-004, Appendix M). All interviews and tests were performed by the primary researcher who, along with the instructors of the exercises sessions, is a qualified clinical exercise therapist (Biokineticist) registered with the Health Professions Council. Personal and disease-specific information for descriptive purposes were obtained by means of an information form and interviews. Testing of outcome measures was performed at baseline and after eight-weeks at post-intervention (45-90 minutes per visit) in the same order, at a similar time and with the same equipment. An offsite, uninvolved individual performed 1:1 concealed randomization at each of the three locations and consigned participants into two groups. Both groups had to complete 24 exercises sessions which focused on gait retraining; however, one

group performed exercises in the forward direction (control group, FWG n=15) and the other in the backward direction (experimental group, BWG n=16). Due to the type of training tasks used, participants could not be completely blinded to the main aim of the study; however, no testing results were shared with participants and the outcome variables were not discussed until after completion of the study.

4.3.2 Participation criteria

Participants were under stable dosage of anti-Parkinson medications (Appendix C) and instructed to use their medication as usual. At the time of testing, an average of three hours past following medication dose.

Table 4.1 Participation criteria

Inclusion criteria	Exclusion criteria
• Mild to moderate PD (H&Y stages 1-3) [30] • Ambulate independently for 3 meters (assistive devices such as a walking stick was accepted) • Stable medication usage (no changes over study period) • Age: 45-86 years • Any level of training, disease duration and geographical background • Transport to and from testing and training locations	• Injury requiring medical attention within the last three months before the onset of the intervention • History or evidence of severe cognitive deficit – a score of <17 on the Montreal Cognitive Assessment [31] • Neurological, cardiovascular or musculoskeletal disease or impairment other than PD • Previous training in backwards walking

4.3.3 Evaluations

At baseline, global cognition (Montreal Cognitive Assessment; MoCA), age, height, body mass and disease-related history was assessed for descriptive purposes. Additionally, disease severity stage (H&Y stage) was determined from the motor examination to categorize participants into mild (stage II) or moderate (stage III) PD [30]. During each testing session, participants completed the instrumented Five-times-Sit-to-Stand test and Timed-Up-and-Go under both ST and DT conditions. The primary researcher performed all the evaluations and showed excellent test-retest reliability in the iTUG (r=0.89, p=0.58) and i5xSTS (r=0.99, p=0.15) tests. The primary outcome variables were turning variables (iTUG) as well as postural transition variables

i.e. sit-to-stand (i5xSTS) and stand-to-sit (iTUG) duration together with the percentage DT cost (%DTC). Before each testing session, participants were asked to complete questionnaires to obtain the secondary outcome measures i.e. motor severity with the Movement Disorder Society-Unified Parkinson's Disease Rating Scale (MDS-UPDRS III, including H&Y stage for disease severity), the mobility domain of the Parkinson's Disease Questionnaire-39 (PDQ-39), freezing status and gait difficulties with the Freezing of Gait Questionnaire (FOG-Q, Appendix I) and balance confidence via the Activity-specific Balance Confidence (ABC, Appendix G) scale.

a) Equipment

Mobility Lab (APDM®, Beta version, Portland, OR, USA) equipment was used to objectively track movement with Opal inertial sensors. Each sensor is the size of a wrist watch (dimensions: 48.4mm x 36.1mm x 13.4mm) and contains an accelerometer, gyroscope and magnetometer that is used to obtain spatio-temporal information, which is transmitted at a frequency of 2.40-2.48 GHz [32]. This inertial system is comparable to a gold-standard Vicon motion analysis system (Vicon, Oxford Metrics Group, Oxford, UK) during locomotor activities in individuals with PD [33]. Desirable sensitivity, reliability and validity of gait variables and mobility in PD during prescribed motor tasks have been reported by using three-dimensional analyses, force plates and electromyograms [7,34,35]. Participants were equipped with six Mobility Lab inertial sensors [32]. After demonstrating and checking for understanding, participants performed two trials each of the iTUG and i5xSTS tests under ST and DT conditions, with 30-60 seconds rest between trials. Data were exported to into Excel 2010 (Microsoft®, Microsoft Corporation, USA) and the average ST and DT measures for each test was used for further analyses.

b) Five-Times-Sit-to-Stand

For the i5xSTS, a standard chair (43cm in height, no armrests) was used. Participants were instructed to stand up and sit down five times after one another as fast and as safely as possible without the use of their arms (*Figure 4.1a*) [36]. This test has been reported to be a valid (ICC=0.99) and reliable (ICC=0.64-0.96) measure of functional mobility in PD [36]. The total duration and average time to perform a sit-to-stand transition was recorded.

c) Timed-Up-and-Go

For the iTUG, the same standard chair as the i5xSTS was used and participants were instructed to perform the iTUG as illustrated in *Figure 4.1b* [37]. A TUG test has shown to be an effective to evaluate mobility performance in PD (ICC=0.85; r=0.99) [38], with desirable sensitivity (0.69) and specificity (0.62) to distinguish between fallers and non-fallers in PD [5]. The iTUG

specifically has been compared with a motion analysis system in a gait laboratory with PD individuals and has shown to be valid, reliable and sensitive measure of functional mobility, even though a 7m protocol was used [7,39,40]. Apart from iTUG duration, stand-to-sit duration was also recorded.

d) Turning

The iTUG, as previously described, was used to obtain turning paramters i.e. turning duration, velocity and angle.

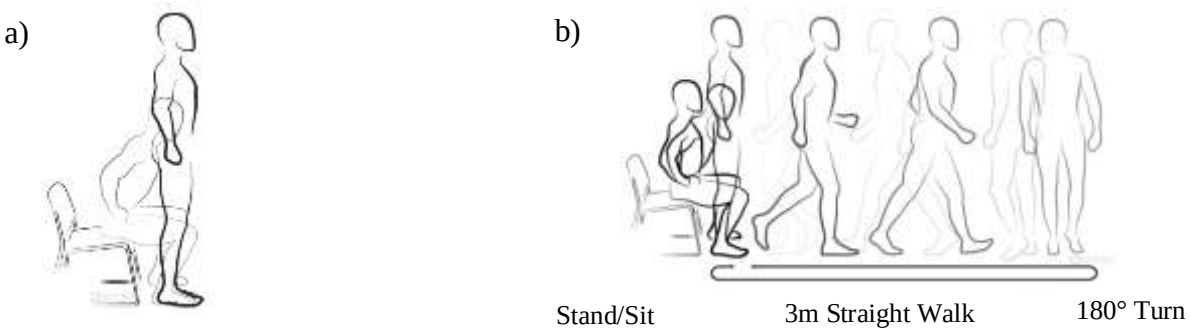


Figure 4.1 Illustration of protocols used: a) Intrumented Five-times Sit-to-Stand; b) Intrumented Timed-Up-and-Go (with permision APDM©)

e) Dual tasking

Fuller et al. (2013) as well as Atterbury (2016) stated that in early PD, mobility difficulties are sometimes not demonstrated under ST conditions; however, impairments become evident under DT conditions. Consequently, evaluating PD individuals while DT gives an better indication of the underlining mobility impairments and fall risk [43]. Therefore, doing DT testing is an ecological valid way to assess mobility impairments.

For the DT trials, participants performed an arrhythmic task – serial three subtractions (counting backwards by three's aloud) from a randomly selected 100th between 100 and 1000 (100, 200, 300…) [44,45]. It has been reported that a verbal-cognitive task causes gait interference in PD individuals [46]. To avoid the learning effect during the post-testing, the number with which participants subtracted by, was also randomized to any number between two and ten. The proportion difference between ST and DT performance, referred to as dual task interference, or cost (%DTC), was calculated with the following formula (Plummer & Eskes, 2015):

$$\%DTC = \frac{(DT\ performance - ST\ performance)}{ST\ performance} \times 100$$

For parameters where worse performance is indicated by higher values, a negative sign was inserted before the equation. Negative values indicate deterioration in the DT relative to the ST and positive values indicate a relative improvement in DT performance, compared to ST [47].

f) Secondary outcome measures

To assess motor symptom severity, participants completed part III of the MDS-UPDRS (r=0.96) [48]. For each participant, their individual PD symptom scores (bradykinesia, rigidity, tremor, postural instability) were calculated [49]. To differentiate between tremor dominant (TD) and postural instability and gait difficulty (PIGD) individuals, the mean of specific items on the MDS-UPDRS, which relates to TD or PIGD respectively, was used to calculate a differentiation ratio with the following formula [50]:

$$\bar{x}_1 = \frac{2.10+3.15a+3.15b+3.16a+3.16b+3.17a+3.17b+3.17c+3.17d+3.17e+3.18}{11}$$

$$\bar{x}_2 = \frac{2.12 + 2.13 + 3.10 + 3.11 + 3.12}{5}$$

Differentiating ration = $\frac{\bar{x}_1}{\bar{x}_2}$

If the ratio is ≥1.15, the participant is TD. If the ratio is ≤0.90, the participant has PIGD. Individuals with a ratio between 0.90 and 1.15 are categorized as indeterminate [50]. Also, individual PD symptom (bradykinesia, rigidity, tremor, postural instability) scores were calculated [49].

The PDQ-39 is a validated (r=0.72) and reliable (ICC=0.95) questionnaire to for disease-related QoL in PD individuals [51] and is used to determine mild treatment effects on different PD-related domains [37]. For this article, only the mobility domain was used, as it correlates with turning velocity [6,52].

To detect loss of balance confidence and fall risk, the ABC scale, which is valid (r= –0.66) and reliable (ICC=0.94) for PD individuals, was used [38]. As balance confidence correlates with turning velocity [6], ABC scores were included as a secondary measure.

The FOG-Q is validated to identify 85.9% of PD freezers (r=0.84) [36]. This questionnaire reports on self-reported gait difficulties, freezing episodes and how it may affect independence. As turning is the most frequent trigger of freezing in PD [53], this questionnaire was included and also used to distinguish between those participants who experience FOG and those who don't.

4.3.4 Training intervention

The objectives for the training program was the same for the FWG and BWG, as outlined in *Figure 4.2* [20,25,53–61]. There were three different warm-up and cool-down protocols, which were alternated between sessions. Participants were instructed to focus on different gait-related aspects and to utilize different types of cues while walking.

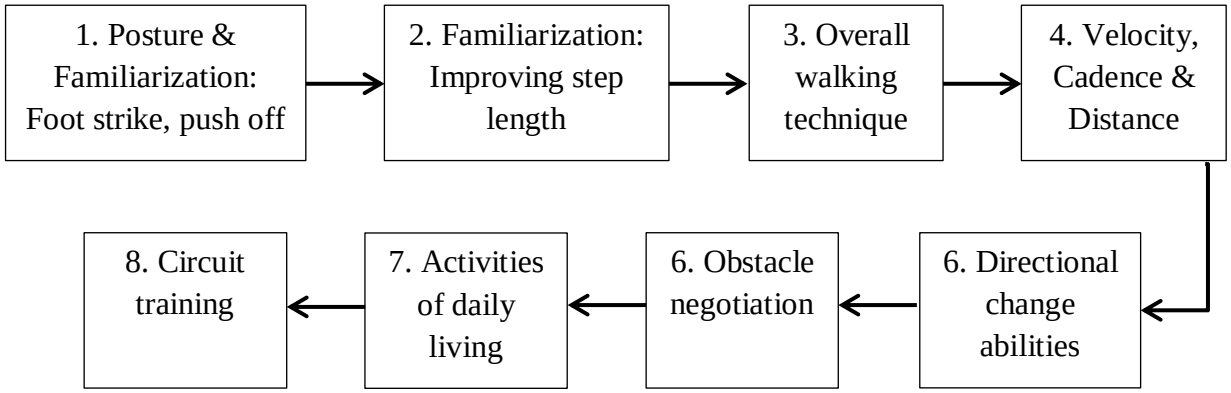


Figure 4.2 Outline of training program with weekly objectives

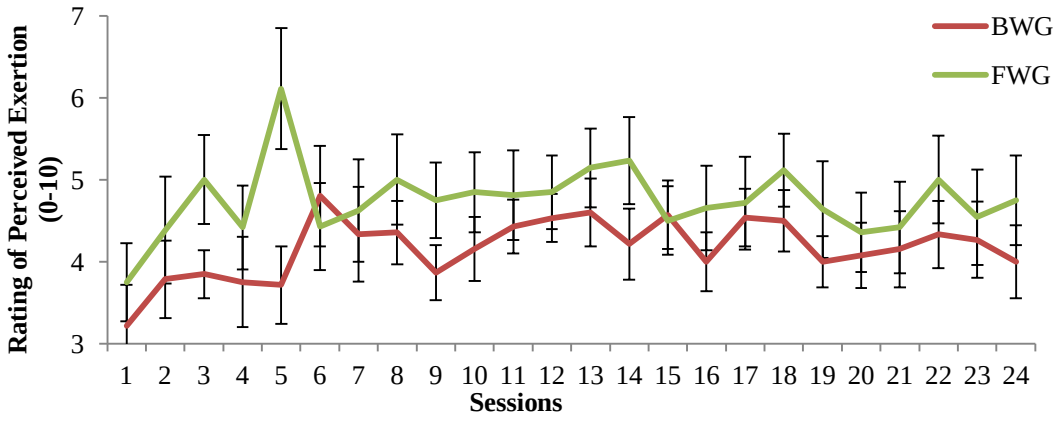
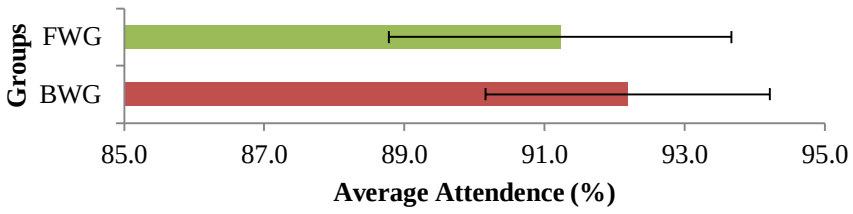
Abbruzzese et al. (2016) recently suggested that rehabilitation should be complex and include functional tasks to realistically mirror real life. Thus, by adding secondary tasks, more cognitive resources are recruited to thereby also train executive control of mobility [63]. Therefore, exercises were progressed by adding different types of cognitive, verbal or motor DT to gait tasks and different obstacles. Both groups performed the same type of DT, which were different than what was used during testing. A summary of the training program is provided in Appendix A.

At the end of each session, participants were asked to give a Rating of Perceived Exertion (RPE) by using the 0-10 Borg Scale. More information on the intervention is outlined in *Table 4.2*.

4.3.5 Data analysis

Based on data (SL, gait speed, cadence) from a preliminary study done by the same laboratory, a statistician recommended a sample size of 40 participants to reach a statistical power of 80% (α=0.05) and an estimated moderate effect size (d=0.60) [42,64]. Data were assessed for normality using the results from the Shapiro-Wilks test and QQ plots. All data were found to be reasonably normally distributed; therefore, parametric tests were used and a Chi^2 test for categorical variables. For non-parametric data (RPE), a Mann-Whitney-U test was used. Time was the within-subjects factor and the group to which participants were allocated (randomization) was the between-subjects factor.

Table 4.2 Eight-week gait retraining program details

Parameter	Information
Setting	Sessions were held indoors on a hard surface next to chairs and walls to which participants could hold on to. Participants were instructed to wear the same, standard footwear as during testing sessions.
Frequency	3x / week (24 sessions)
Duration	Total: 45-60 minutes per session ▪ 20-30 minutes over ground gait retraining ▪ 5-10 minutes of other activities (warm-up, reaching, relaxation, etc.) ▪ 5-10 minutes stretching
Type of activities	• Walking while focusing on different gait-related aspects • Utilizing different types of cues • Negotiating different obstacles • Adding motor tasks • Adding cognitive tasks
Groups	FWG: performed the different gait tasks in the forward direction BWG: performed the different gait tasks in the backward direction
Intensity	
Attendence	

Where there was a significant TIME-effect, but no GROUP or GROUPxTIME effect, post hoc analysis was conducted on the pooled sampled, using Fisher exact LSD tests. Mobility Lab

parameters were extracted and organized using Excel 2010 (Microsoft®). Participant characteristics and mobility performance at pre- (baseline) and post-testing as well as over time were summarized with descriptive statistics by reporting means, standard deviations and 95% confidence intervals (CI) or number of observations (*f*) and percentages for qualitative data. Possible significant differences were investigated with Statistica® software (version 13, StatSoft, Inc., Tulsa, USA) for Windows. The alpha level was set at greater than 0.05 and tendencies smaller than 0.10. Furthermore, Cohen's effect sizes were calculated to determine small, medium and large practical significance (0.15, 0.40 and 0.75, respectively) [65].

4.4 Results

Of the 31 eligible individuals, two did not complete the intervention i.e. due to injury (FWG) and illness (BWG). The remaining 29 participants completed >77% of the 24 sessions, with an average attendance rate of 91.2±9.2% in the FWG and 92.2±7.9% in the BWG. Participants of the FWG (n=14) and BWG (n=15) had no differences in baseline descriptive characteristics (*Table 4.3;* p>0.05). A summary of main- and interaction-effects of descriptive variables are outlined in Appendix O1.

Table 4.3 *Participant descriptive variables. Values are mean ± standard deviation (95% CI), except where indicated otherwise*

Variable	FWG (n = 14)	BWG (n = 15)	p ; Effect Size
Age (years)	70.0 ± 11.0 (6.5)	72.0 ± 6.0 (3.4)	p = 0.53; *d* = 0.24^{S}
Gender (*f*)			
Men (%)	10 (71.4)	9 (60.0)	p = 0.52
Women (%)	4 (28.6)	6 (40.0)	
Height (cm)	169.6 ± 11.9 (6.9)	167.4 ± 8.4 (4.6)	p = 0.56; *d* = 0.22^{S}
Body Mass (kg)	77.4 ± 12.9 (7.5)	75.3 ± 17.0 (9.4)	p = 0.72; *d* = 0.14^{N}
Hoehn & Yahr (*f*)			
Stage 2 (%)	4.0 (28.6)	5.0 (33.3)	p = 0.78
Stage 3 (%)	10.0 (71.4)	10.0 (66.7)	
Years since diagnosis (years)	7.0 ± 6.0 (3.6)	5.0 ± 3.0 (1.7)	p = 0.21; *d* = 0.44^{M}
Type of PD (*f*)			
TD (%)	4 (28.6)	7 (46.7)	p = 0.42
PIGD (%)	9 (64.3)	6 (40.0)	
Indeterminate (%)	1 (7.2)	2 (13.3)	
Global Cognition (MoCA)	24.3 ± 2.1 (1.2)	23.1 ± 2.8 (1.5)	p = 0.20; *d* = 0.50^{M}
Freezing status (*f*)			
Freezers (%)	11 (78.6)	10 (66.7)	p = 0.47
Non-Freezers (%)	3 (21.4)	5 (33.3)	

Effect sizes: ^{N}Negligible, ^{S}Small, ^{M}Medium; Abbreviations: *f* = number of observations; TD = Tremor dominant, PIGD = Postural instability and gait difficulty, MoCA = Montreal Cognitive Assessment

All main- and interaction-effects of outcome variables are summarized in Appendix O2. Post hoc analysis for the outcome variables over time and between groups are outlined in *Table 4.4* and *4.5*. There was a between-group difference at baseline for i5xSTSST and iTUG^{DT} duration (p=0.05 and p=0.02, respectively) where the FWG performed worse, as shown by post hoc analysis.

Table 4.4 *Secondary outcome variables of the FWG (n=14) and BWG (n=15) reported as mean ± standard deviation (95% CI)*

Variable	Pre-intervention	Post-intervention	p ; Effect Size
MDS-UPDRS Motor score (Part III)			
FWG	40.7 ± 14.7 (8.5)	36.1 ± 3.7 (4.9)	$^{3}p = 0.02$*; $^{3}d = 0.45^{M}$
BWG	35.6 ± 9.5 (5.3)	31.4 ± 2.8 (6.0)	$^{4}p = 0.03$*; $^{4}d = 0.62^{M}$
	$^{1}p = 0.27$; $^{1}d = 0.43^{M}$	$^{2}p = 0.32$; $^{2}d = 1.49^{H}$	
Quality of life: PDQ-39 Mobility			
FWG	37.0 ± 22.8 (13.2)	30.2 ± 22.8 (13.1)	$^{3}p = 0.12$; $^{3}d = 0.31^{S}$
BWG	35.5 ± 32.7 (18.1)	24.0 ± 24.9 (13.8)	$^{4}p = 0.01$; $^{4}d = 0.41^{M}$
	$^{1}p = 0.88$; $^{1}d = 0.05^{N}$	$^{2}p = 0.53$; $^{2}d = 0.27^{S}$	
Balance Confidence (ABC score)			
FWG	64.6 ± 22.7 (13.1)	70.0 ± 17.3 (10.0)	$^{3}p = 0.22$; $^{3}d = 0.03^{S}$
BWG	67.3 ± 25.9 (14.4)	70.6 ± 25.0 (13.8)	$^{4}p = 0.34$; $^{4}d = 0.13^{N}$
	$^{1}p = 0.75$; $^{1}d = 0.11^{N}$	$^{2}p = 0.85$; $^{2}d = 0.03^{N}$	
Freezing of gait (FOG-Q)			
FWG	9.5 ± 4.7 (2.7)	7.4 ± 5.8 (3.4)	$^{3}p = 0.08$^; $^{3}d = 0.30^{S}$
BWG	7.8 ± 6.5 (3.6)	6.1 ± 5.2 (2.9)	$^{4}p = 0.14$; $^{4}d = 0.41^{M}$
	$^{1}p = 0.42$; $^{1}d = 0.31^{S}$	$^{2}p = 0.54$; $^{2}d = 0.25^{S}$	

*p<0.05, ^p<0.09; Effect sizes: ^{N}Negligible, ^{S}Small, ^{M}Medium, ^{H}Huge; ^{1}Group difference at baseline, ^{2}Group difference at post-test, ^{3}FWG difference over time, ^{4}BWG difference over time; Abbreviations: MDS-UPDRS = Movement Disorder Society – Unified Parkinson's Disease Rating Scale; PDQ-39 = Parkinson's Disease Questionnaire – 39, ABC = Activity Specific Balance Confidence, FOG-Q = Freezing of Gait Questionnaire

4.4.1 Five-Times-Sit-to-Stand

A positive TIME-effect was seen for i5xSTSST duration (p=0.02). Post hoc analysis showed within-group improvement of 12.3% for i5xSTSST duration of the FWG (p=0.01). No GROUPxTIME (interaction) effects were found under ST conditions for i5xSTS total duration (p=0.12) or for sit-to-stand duration (p=0.86).

4.4.2 Timed-Up-and-Go

During the iTUGST, a positive TIME-effect (p<0.01) without a GROUPxTIME interaction (p=0.19) was observed for total duration. Post hoc analysis showed within-group improvement of 16.5% for iTUGST duration in the FWG (p<0.01). Neither the FW nor the BW intervention induced changes in stand-to-sit duration under ST conditions (GROUPxTIME: p=0.95).

Table 4.5 *Transitional movements under single task and dual task conditions for the FWG (n=14) and BWG (n=15). Values are mean ± standard deviation (95% CI). For dual task cost, negative values indicate worse performance under dual task conditions.*

Variable	*Single Task*			*Dual Task*			*Dual Task Cost*		
	Pre-intervention	**Post-intervention**	**p; Effect Sizes**	**Pre-intervention**	**Post-intervention**	**p; Effect Sizes**	**Pre-intervention**	**Post-intervention**	**p; Effect Sizes**
Functional Mobility									
[A]i5xSTS Duration (s) FWG BWG	25.3 ± 14.0 (8.1) 18.2 ± 5.7 (3.2) [1]p = 0.05*; [1]*d* = 0.70[M]	19.6 ± 6.0 (3.5) 17.6 ± 4.6 (2.6) [2]p = 0.53; [2]*d* = 0.39[S]	[3]p < 0.01*; [3]*d* = 0.52[M] [4]p = 0.49; [4]*d* = 0.12[N]	36.8 ± 28.5 (17.2) 25.2 ± 9.8 (5.5) [1]p = 0.14; [1]*d* = 0.58[M]	33.6 ± 19.2 (11.1) 29.3 ± 19.7 (10.9) [2]p = 0.57; [2]*d* =0.23[S]	[3]p = 0.56; [3]*d* = 0.14[N] [4]p = 0.40;s [4]*d* = 0.27[N]	-48.3 ± 77.2 (46.6) -33.5 ± 39.7 (22.0) [1]p = 0.67; [1]*d* = 0.25[S]	-69.1 ± 87.6 (50.6) -69.7 ± 115.6 (64.0) [2]p = 0.99; [2]*d* = 0.01[N]	[3]p = 0.44; [3]*d* = 0.26[S] [4]p = 0.18; [4]*d* = 0.43[M]
[B]iTUG Duration (s) FWG BWG	20.4 ± 8.0 (4.6) 16.9 ± 6.5 (3.6) [1]p = 0.13; [1]*d* = 0.50[M]	16.0 ± 4.3 (2.5) 14.9 ± 4.3 (2.4) [2]p = 0.63; [2]*d* = 0.27[S]	[3]p < 0.01*; [3]*d* = 0.71[M] [4]p = 0.14; [4]*d* = 0.38[S]	32.9 ± 22.3 (12.9) 21.3 ± 6.8 (3.8) [1]p = 0.02*; [1]*d* = 0.74[M]	24.0 ± 9.6 (5.5) 21.2 ± 5.6 (3.1) [2]p = 0.56; [2]*d* = 0.37[S]	[3]p = 0.02*; [3]*d* = 0.54[M] [4]p = 0.98; [4]*d* = 0.02[N]	-70.5 ± 129.5 (74.8) -31.1 ± 38.1 (21.1) [1]p = 0.17; [1]*d* = 0.43[M]	-47.5 ± 39.4 (22.7) -49.9 ± 54.2 (30.0) [2]p = 0.93; [2]*d* = 0.05[N]	[3]p = 0.38; [3]*d* = 0.25[S] [4]p = 0.46; [4]*d* = 0.42[M]
Postural Transitions									
[A]Sit-to-Stand Duration (s) FWG BWG	1.5 ± 0.6 (0.4) 1.7 ± 0.9 (0.5) [1]p = 0.79; [1]*d* = 0.27[S]	1.6 ± 0.5 (0.3) 1.6 ± 0.6 (0.3) [2]p = 0.90; [2]*d* = 0.00[N]	[3]p = 0.97; [3]*d* = 0.19[S] [4]p = 0.76; [4]*d* =0.14[N]	1.7 ± 0.5 (0.3) 1.7 ± 0.4 (0.2) [1]p = 0.71; [1]*d* = 0.00[N]	1.5 ± 0.5 (0.3) 1.7 ± 0.5 (0.3) [2]p = 0.17; [2]*d* = 0.41[M]	[3]p = 0.11; [3]*d* = 0.42[M] [4]p = 0.99; [4]*d* = 0.00[N]	-20.8 ± 20.9 (15.0) -13.2 ± 30.4 (16.9) [1]p = 0.54; [1]*d* = 0.30[S]	-7.5 ± 22.2 (14.9) -11.1 ± 25.4 (14.1) [2]p = 0.72; [2]*d* = 0.16[S]	[3]p = 0.20; [3]*d* = 0.64[M] [4]p = 0.79; [4]*d* = 0.08[N]
[B]Stand-to-Sit Duration (s) FWG BWG	1.3 ± 0.3 (0.2) 1.3 ± 0.2 (0.1) [1]p = 0.56; [1]*d* = 0.00[N]	1.2 ± 0.3 (0.2) 1.2 ± 0.2 (0.1) [2]p = 0.61; [2]*d* = 0.00[N]	[3]p = 0.37; [3]*d* = 0.35[S] [4]p = 0.38; [4]*d* = 0.52[M]	1.4 ± 0.4 (0.2) 1.2 ± 0.2 (0.1) [1]p = 0.20; [1]*d* = 0.66[M]	1.2 ± 0.3 (0.2) 1.2 ± 0.3 (0.2) [2]p = 0.83; [2]*d* = 0.07[N]	[3]p = 0.10; [3]*d* = 0.59[M] [4]p = 0.90; [4]*d* = 0.00[N]	-3.9 ± 14.2 (8.6) 1.0 ± 16.2 (9.8) [1]p = 0.50; [1]*d* = 0.33[S]	4.0 ± 17.0 (11.4) -2.4 ± 23.5 (13.5) [2]p = 0.40; [2]*d* = 0.32[S]	[3]p = 0.30; [3]*d* = 0.52[M] [4]p = 0.64; [4]*d* = 0.17[S]
Turning									
[B]Turn Duration (s) FWG BWG	2.7 ± 0.7 (0.4) 2.4 ± 0.5 (0.3) [1]p = 0.19; [1]*d* = 0.51[M]	2.6 ± 0.6 (0.3) 2.3 ± 0.5 (0.3) [2]p = 0.21; [2]*d* = 0.56[M]	[3]p = 0.53; [3]*d* = 0.16[S] [4]p = 0.57; [4]*d* = 0.21[S]	2.7 ± 0.6 (0.3) 2.5 ± 0.4 (0.2) [1]p = 0.40; [1]*d* = 0.41[M]	2.9 ± 0.8 (0.5) 2.5 ± 0.5 (0.3) [2]p = 0.10; [2]*d* = 0.63[M]	[3]p = 0.25; [3]*d* = 0.29[S] [4]p = 0.91; [4]*d* = 0.00[N]	-3.9 ± 17.2 (9.9) -8.3 ± 17.9 (9.9) [1]p = 0.59; [1]*d* = 0.23[S]	-11.3 ± 24.1 (13.9) -11.7 ± 26.2 (14.5) [2]p = 0.96; [2]*d* = 0.02[N]	[3]p = 0.37; [3]*d* = 0.37[S] [4]p = 0.66; [4]*d* = 0.16[S]
[B]Turn Velocity (°/s) FWG BWG	132.1 ± 44.6 (25.8) 150.0 ± 39.2 (21.7) [1]p = 0.26; [1]*d* = 0.44[M]	144.0 ± 43.6 (25.2) 160.7 ± 41.0 (22.7) [2]p = 0.29; [2]*d* = 0.41[M]	[3]p = 0.04*; [3]*d* = 0.28[S] [4]p = 0.05*; [4]*d* = 0.28[S]	114.8 ± 46.7 (26.9) 133.3 ± 42.6 (23.6) [1]p = 0.26; [1]*d* = 0.43[M]	127.2 ± 50.4 (20.1) 129.2 ± 33.8 (18.7) [2]p = 0.90; [2]*d* = 0.05[N]	[3]p = 0.07^; [3]*d* = 0.26[S] [4]p = 0.53; [4]*d* = 0.11[N]	-14.3 ± 12.8 (7.4) -10.8 ± 15.6 (8.6) [1]p = 0.57; [1]*d* = 0.25[S]	-13.1 ± 13.5 (7.8) -17.1 ± 21.5 (11.9) [2]p = 0.52; [2]*d* = 0.23[S]	[3]p = 0.82; [3]*d* = 0.09[N] [4]p = 0.21; [4]*d* = 0.35[S]
[B]Turn Angle (°) FWG BWG	159.0 ± 19.4 (11.2) 161.2 ± 17.3 (9.6) [1]p = 0.71; [1]*d* = 0.12[N]	167.11 ± 12.1 (7.0) 166.3 ± 12.2 (6.7) [2]p = 0.89; [2]*d* = 0.07[N]	[3]p = 0.02*; [3]*d* = 0.52[M] [4]p = 0.10; [4]*d* =0.35[S]	142.5 ± 28.0 (16.2) 153.2 ± 24.4 (13.5) [1]p = 0.26; [1]*d* = 0.42[M]	156.7 ± 18.6 (10.7) 151.0 ± 27.9 (15.5) [2]p = 0.55; [2]*d* = 0.25[S]	[3]p = 0.01*; [3]*d* = 0.62[M] [4]p = 0.64; [4]*d* = 0.09[N]	-9.8 ± 16.9 (9.7) -5.1 ± 10.2 (5.6) [1]p = 0.34; [1]*d* = 0.35[S]	-6.0 ± 10.8 (6.2) -9.7 ± 13.2 (7.3) [2]p = 0.46; [2]*d* = 0.32[S]	[3]p = 0.35; [3]*d* = 0.28[S] [4]p = 0.24; [4]*d* = 0.40[M]

*p<0.05, ^p<0.09; [A]i5xSTS, [B]iTUG; [1]Group difference at baseline, [2]Group difference at post-test, [3]FWG difference over time, [4]BWG difference over time; Effect sizes: [N]Negligible, [S]Small, [M]Medium; Abbreviations: i5xSTS = Instrumented Five-times Sit-to-Stand, iTUG = Instrumented Timed Up-and-Go

4.4.3 Turning

Neither the FW nor the BW intervention induced changes in ST turning duration (GROUPxTIME: p=0.95). Turn velocity under ST conditions demonstrate a significant TIME-effect (p=0.01). At post-testing, within-group improvements in both the FWG (12.2%) and BWG (8.7%) was found for ST turn velocity (p=0.04 and p=0.05, respectively). Over time with participants grouped together (TIME-effect), ST turn angle improved (p=0.01), with no GROUPxTIME interaction (p=0.51). Post hoc analysis showed a within-group improvement of 6.2% for ST turn angle in the FWG (p=0.02).

4.4.4 Dual Tasking

Under DT conditions, no GROUPxTIME (interaction) effects were found for i5xSTS^{DT} duration (p=0.32), sit-to-stand transitions (p=0.21), iTUG^{DT} stand-to-sit transitions (p=0.20), turning duration (p=0.36) or turning velocity (p=0.08). With the iTUG^{DT} duration, a weak trend towards a TIME-effect was observed (p=0.09), without a GROUPxTIME interaction (p=0.10). Post hoc analysis showed a within-group improvement of 24.0% for iTUG^{DT} duration in the FWG (p=0.02). For DT turn angle, a GROUPxTIME interaction (p=0.02) was found. This interaction is shown over time as within-group improvement of 13.3% for turn angle in the FWG under DT conditions (p=0.01). Analysis of %DTC yielded insignificant results for all variables (p>0.05).

4.4.5 Secondary outcome variables

A significant TIME-effects was seen for UPDRS III and bradykinesia (both p<0.01), but no GROUPxTIME effects (p=0.87 and p=0.37, respectively). Post hoc analysis demonstrated that the FWG and BWG improved UPDRS III scores by 11.0% and 11.4%, respectively (p=0.02 and p=0.03, respectively) as well as bradykinesia scores by 23.6% and 12.2%, respectively (p<0.01 and p=0.01, respectively) in response to their respective interventions. Main-effects for rigidity included a TIME-effect (p=0.01) and GROUP-effect (p=0.04), but not GROUPxTIME interaction (p=0.76). After post hoc analysis, it became clear that the FWG significantly increased (worsened) their rigidity scores by 45.2% (p=0.05), which yielded a between-group difference (p=0.04) at post-testing. A TIME-effect (p<0.01) was found for the PDQ-39 Mobility domain (GROUPxTIME: p=0.43), yielding a 64.9% within-group improvement for the BWG with post hoc analysis (p=0.01). No changes were found for ABC scores (GROUPxTIME: p=0.82).

4.5 Discussion

This article aimed to make a comparison of an eight-week forward and backward gait retraining program on postural transitions and turning of PD individuals as well as dual task interference on these parameters. Participants in this study had similar baseline scores for descriptive variables. For clinical variables at baseline, total duration in the i5xSTSST as well as the iTUG^{DT} total duration differed between the two groups, where the FWG performed worse. For both these two variables, the FWG improved their time but no group differences were seen at post-testing. In response to the intervention, the FWG also improved the iTUGST total duration, ST turn velocity as well as ST and DT turn angle; whereas the BWG only improved ST turn velocity. Considering secondary outcomes, severity of motor symptoms (MDS-UPDRS III) and bradykinesia for both groups improved over time. Additionally, the BWG improved their PDQ-39 Mobility domain towards post-testing. There was a difference in rigidity scores at post-testing due to worse scores in the FWG.

The MDS-UPDRS Part III is a PD-specific scale for disease related motor symptoms. According to this scale, the average annual deterioration of motor symptoms is approximately 2.2 points [66]. The FWG and BWG improved their motor scores with 4.6 (11.0% improvement, p=0.02) and 4.2 (11.4% improvement, p=0.03) points, respectively. This demonstrates the positive clinical impact of both the forwards and backwards gait retraining programs.

The FWG significantly worsened their rigidity scores, which possibly reflects the natural course of the disease and is further supported by the huge practical significant difference for worse disease severity scores of the FWG at post-testing. Although the natural course of the disease should obviously also have affected the BWG, their rigidity scores remained unchanged. It is possible that the nature of BW combated this inevitable decline in muscle stiffness. As the foot is placed behind the body with BW, hip extension is facilitated [24] to thereby actively stretch the hip flexors during walking. Also, hamstring flexibility has been reported to increase after a four-week BW intervention for young athletes with low back pain [67]. Moreover, in response to fear of falling and task-specific visual restrictions, BW participants often twisted their bodies and heads every few meters to view their walking path. These motions were not made with FW and could also explain between-group differences in rigidity at post-testing.

The impact of postural instability that relates to impaired balance during voluntary movements reflects the difficulty that PD individuals have with movement control [10]. It has recently been reported that PD individuals who have more postural instability and gait difficulty (PIGD), have longer TUG durations, slower turning velocities, more severe freezing episodes, longer disease

duration and worse disease symptoms [68]. Moreover, gait retraining programs (as was used in the current study) may be more beneficial for PD individuals with PIGD, compared to tremor dominant individuals, as it directly addresses their dominant impairment. Results of the current study were however not divided between PD sub-types. Future studies should consider a large enough power to clarify this aforementioned relationship.

4.5.1 Five-Times-Sit-to-Stand

Standing up from a seated position and vice versa is, from a mechanical and musculoskeletal perspective, the most demanding task during activities of daily living (ADL) [69]. The 5xSTS is a valid measure of dynamic balance functional mobility in PD [36]. On the 5xSTS, an optimal cut-off time for fall risk in healthy elderly (age 74.9±7.0 years) was 16.9 seconds [70], which is close to the PD specific cut-off score of 16.0 seconds [36]. According to these cut-off scores, all participants of the current study were at risk of falling before and after the intervention, even though the risk for both groups decreased in response to the training program. A mean detectable change of >2.5 seconds was seen in the FWG, but not in the BWG for 5xSTS performance.

At baseline however, the FWG took longer to complete the i5xSTS. This can be related to the FWG having worse rigidity scores than the BWG at baseline, as shown by a moderate trend, but large practical significant difference. It is well known that rigidity restricts movement [10], specifically by impairing hip extension [10]. Considering that hip extension is required for a chair transfer as well as to produce adequate SL, worse rigidity in the FWG may explain their longer i5xSTS durations. This baseline duration of the i5xSTS was also worse than a previously reported score of 20.25±14.12 seconds in similar PD individuals [36]. In response to the FW training program, the FWG improved mobility beyond that of the BWG, to a score that is similar to the BWG at post-testing. The effect of PD itself on mobility performance is highlighted with these results as a previous study on older individuals (aged 73.0±5.0 years) with a variety of balance impairments scored 16.4±4.4 seconds on a 5xSTS test [1].

These findings are opposite to what has been expected for BW gait retraining in PD as literature suggests that BW training in healthy individuals can improve quadriceps muscle strength and postural transitions [16,15]. Strength of the lower limb muscles plays an important role in the control of upright stability in PD [14]. However, Duncan et al. (2011) demonstrated that lower extremity muscle strength does not related to 5xSTS performance in PD as strongly as in other populations. Compared to healthy elderly, PD individuals take longer to perform a STS transfer [61], presumably due to PD-related balance impairments, bradykinesia and rigidity [36,69]. In the current study, no changes were found in perceived balance confidence while both groups

improved bradykinesia scores. Taken together, the addition of a structured physical exercise program improved bradykinetic symptoms; while the specificity of only the FW gait retraining program yielded superior results for functional mobility on the i5xSTS. Consequently, it seems that benefits from BW in PD are different from that of healthy individuals.

A recent study noted reduced postural control while performing a sit-to-stand transition in PD [61]. Performance on sit-to-stand transitions involves anticipatory postural adjustments, which is exacerbated in moderate PD and manifested as greater forward displacement in center of pressure with increased momentum to compensate for slowness and posterior instability and reduce the risk of backward falls [61,71]. This strategy however decreases their forward stability at the braking phase of standing up, increasing their risk of falling at movement termination [71].

In contrast to what was expected, results from the current study illustrates that BW does not have an effect on 5xSTS performance, showing that BW gait retraining does not relate to backward stability during transitional movements. It was presumed that the eccentric nature of BW may induce mobility improvements; however improved eccentric control with training seems to have an effect only on stand-to-sit transitions [69], which remained unchanged in the current study. Conversely, FW training might have induced superior improvement to overall stability by minimizing backward instability at movement initiation as well as forward instability at movement termination. This mechanism was reported by Bhatt et al. (2013) who performed a four-week audio-visually cued training program (20min, 3x/week) for sit-to-stand performance. A systematic review reported on improvement in sit-to-stand performance in response to rehabilitative training for a variety of populations i.e. healthy young individuals, frail elderly, PD, etc. Different factors relating to improved sit-to-stand performance has shown to be related to improved coordination, increased quickness and muscle strength as well as decreased unsteadiness [69]. Taken together with results from the current study, improvements in the FWG can be attributed to decreased unsteadiness during a sit-to-stand transfer. A six-month balance and lower limb strengthening training program (40-60min, 3x/week) for similarly aged PD individuals (UPDRS III: 29.0±10.0) who had much faster 5xSTS performance, yielded a 1.5% improvement in response to their training [72]. Comparing results from the six-month training program to the current study, it is clear that 5xSTS performance can be improved in PD individuals with more severe motor symptoms by performing a shorter, eight-week, FW training program.

4.5.2 Timed-Up-and-Go

Total time to complete the iTUGST improved only for the FWG. A TUG time of >16 seconds can be associated with an increased fall risk [5]. Before the onset of the intervention, both groups were at risk of falling. At post-testing, the FWG minimized their fall risk; whereas the BWG diminished their fall risk. The 4.4s (16.5%) improvement in iTUGST duration of the FWG was significant, and slightly lower than the previously reported mean detectable change of 4.9s for PD individuals. This slight difference might be attributed to the participants in the current study being older and having longer disease duration, where motor symptoms may have such a larger impact on iTUG performance.

At post-testing, iTUGST duration of participants in the current study is in line with a previous study on PD individuals of similar age [73]; however, PD individuals with less severe UPDRS motor scores (25.2±9.56) scored better than what was reported at post-testing in the current study [74], highlighting the effect of motor severity, which were worse in the current study, on mobility as measured by iTUG duration.Younger PD individuals with less severe motor symptoms had shorter TUG durations (10.0-12.0 seconds) than the current study [75,76].

4.5.3 Turning

It was previously reported that TUG duration does not entirely discriminate PD fallers from non-fallers in the on-state of medication usage, as those with normal TUG durations presented with increased turn duration, decrease turning velocity and increased number of steps during a 180° turn. It is therefore suggested that turning ability rather than TUG duration should be used to identify PD mobility impairments [5].

Turning is a complex and challenging task, especially for PD individuals as it demands changes in body orientation with the presence of impaired dynamic postural stability in small stability margins [77]. It is reported that PD individuals have compromised quality of turning, but not quantity (amount of turns on a daily basis), compared to matched, healthy controls [52]. Deviations in turning parameters can primarily occur in response to the disease (rigidity and bradykinesia associated with defective basal ganglia function) or secondary as compensation to the disease (inability to generate momentum or deficient neuromuscular control that limits muscle force production) [8,78].

Balance confidence (ABC scores), bradykinesia [6], PDQ-39 Mobility domain [77] and UPDRS III scores correlate with turning velocity [6,52]. As no changes were found for ABC scores, improvements in turning velocity for both groups may be related to improved PDQ-39 Mobility

(moderate practical significant improvement for the FWG) or bradykinesia scores. Turning velocity is the strongest turning parameter that correlates with disease severity [6,52]. The FWG had moderate practical significant impairment in turning velocity at pre- and post-testing, compared to the BWG, which may be reflected by the practical differences of UPDRS III scores also at pre- (moderate) and post-testing (huge). Moreover, the FWG had a weak trend towards improved FOG-Q scores. It is well known that turning is the most frequent freezing trigger in PD [53]. Taken together, it seems that both FW and BW gait retraining may indirectly improve turning velocity, by targeting disease-related motor disability, the perception of mobility disability and the perception of freezing and gait difficulties on independence. Turning at higher velocities creates more momentum, which in turn requires more neuromuscular control [8]. Therefore, by controlling momentum under higher velocities, PD individuals more closely meet the associated neuromuscular demands of turning – which was true for both groups post-intervention. The addition of a non-exercising (or different type of exercising) control group could clarify whether these results were specifically due to the intervention.

During turning, PD individuals sacrifice movement speed for balance [5]. In response to the intervention, the improved turning velocities indicate more control of their center of gravity over a changing base of support during the turn [5]. A slower turning velocity decreases the required muscle force to decelerate and redirect the body's center of mass [8]. Improved turning velocity in the FWG may be due to improved muscle force distribution, as indicated by their improved i5xSTS performance. Moreover, improved turning velocity may be as result of enhanced reaction times for faster postural preparatory phases, indicating improved stability, possibly required by BW. As PD individuals have impaired motor planning and difficulty switching between gait and turning (from one motor program to another) [2], improved turning velocity may indicate improved motor control and executive motor function. These mechanisms may have resulted from the respective gait retraining programs, yielding improved turning velocity.

Compared to healthy populations, PD individuals perform shorter turns with smaller angles (turn less sharply) and more steps to compensate for slower turning velocities [4,7]. In the current study, a 6.2% improved turning angle was found in the FWG post-intervention for ST. An on-the-spot turn (small turn angle) at high velocity requires high levels of balance control, which generally is impaired in PD and thereby induce a high fall risk [4]. When faster turns are accompanied by a wider turn arc (larger turn angle), overall turning ability is improved. From these findings, the FWG and BWG utilized different turning techniques at post-testing.

The FWG utilized a more beneficial turning strategy as both turning velocity and turning angle improved. This shows that the FWG gained more control of their centre of gravity over a changing base of support when executing a turn as well as improved motor program control to switch from straight walking to turning, as shown by improved iTUG performance [2,5]. This may be indicative of freeing more degrees of freedom, suggesting improved segmental coordination and postural stability in the FWG, and that task specific training may be more important for improved turning abilities. In contrast, the BWG only improved turning velocity, but had similar turning angle at post-testing. As both groups improved gait speed and turning velocity, it is possible that, despite different motor programs, the control mechanisms of these two parameters are partially related [2,5]. Hulbert et al. (2015) noted that the tighter the turn (i.e. the smaller the turn angle), the more these spatiotemporal characteristics are affected. More specifically, smaller turns at higher velocities produce a greater reduction in step length, which may be an effort to preserve postural stability [79]. Therefore, more compensatory steps are needed to complete the turn, expressing impaired bilateral coordination that is adapted in compensation to postural instability [7]. This turning technique decreases the body's momentum and in turn reduces neuromuscular demands [8]. Taken together, the number of degrees of freedom for which need to be controlled for were reduced to allow the BWG to control their centre of mass while their weight is transferred between lower limbs during the turn [80,81]. It is possible that the BWG either became accustomed to conscious control of stability, or that the training program was not sufficiently long enough to allow them to achieve the required levels of coordination for improved turning [7]. Therefore, the BWG presumably was in the cognitive stage of motor learning; whereas the FWG most likely in the associative stage. In other words, a part of the eight-week program was used by the BWG to become familiarized with BW. During this time, the FWG could focus more on refining their turning skills.

Participants in the current study turned at higher velocities than peak velocities found in healthy elderly of similar age (131.9±0.12°/s) and slightly younger PD individuals with lower UPDRS III scores (124.8±0.29°/s) [7]; whereas results were similar to previously reported peak turning velocity (153.4±46.7°/s) of similarly aged PD individuals [82]. In contrast, possibly due to a slightly higher age and higher UPDRS III scores in the current study, a recent study reported ST turning velocities of higher magnitude (173±37°/s); however, a TUG protocol was not used and participants (age 65.0±6.9 years, UPDRS III 21.0±7.0) were instructed to use as-fast-as-possible speeds [83].

A home-based study across seven days on PD individuals, slightly younger with lower UPDRS III than the current study, reported a mean turning angle of 92.0° [7,52]. Despite a different

protocol used, participants in the current study made use of larger turning angles when executing a 180° turn. Previously, children with CP who received BW training on a treadmill showed improved mediolateral and anterioposterior stability [23]. If this was also true for the BWG in the current study, it did not transfer to turning abilities, which was performed in the forward direction. Again, FW is more task-specific and may therefore more closely relate to turning performance.

Taken together the benefits seen with BW may too be beneficial for mobility, but FW is more task-specific and therefore more closely relate to turning performance.

4.5.4 Dual tasking

It is well known that disease severity and duration have an impact on DT abilities [84]. Comparing ST to DT performance, it is clear from the DT variables that the complexity of a secondary task is proportional to mobility performance under such conditions. In response to the intervention, the FWG improved iTUG^{DT} duration by 15.4% and turning angle by 6.2%. Considering %DTC, no significant results were found for any of the variables at any time point. For iTUG^{DT} duration at baseline, the FWG performed significantly worse than the BWG. As there were no group differences for MoCA at baseline, differences in iTUG^{DT} duration at baseline might be explained by a moderate clinical significant baseline difference in motor scores and disease duration between the FWG and BWG, which indicates worse disease severity in the FWG. Even though backward stepping can be beneficial to mobilize cognitive resources [29], BW gait retraining did not induce improved DT abilities during transitional movements. In contrast, participants who trained in FW possibly became more accustomed to the FW task and could therefore allocate more attentional resources to the secondary task.

At baseline, participants in the FWG performed much worse on the TUG^{DT} (21.5±7.9s) than similarly aged PD individuals. At post-testing, both the FWG and BWG had similar results than what has been reported by Campbell et al. (2003). Even though a different type of DT was used in the current study, they seem to be similarly complex (for the BWG), and perhaps even more complex for the FWG – who have a longer disease duration (indicated by a moderate effect size) that may affect their executive function. Moreover, those with posture and gait deficits requires increased attentional resources to maintain adequate movement control during transitions, which is further compromised during DT, as reported by Campbell et al. (2003). Considering that the FWG is made up by a higher percentage of individuals who predominantly have postural instability and gait difficulties, it might explain why they performed worse than the BWG at baseline and benefitted more from the gait retraining program than the BWG, as indicated with

iTUG duration and turning angle under DT conditions. Due to the small sample size of the current study, analysis was not done on separate PD sub-types to clarify the effect thereof on the outcome of the study. Future studies could address this shortcoming.

Rehabilitation of functional impairments in combination with secondary tasks in PD, may improve their DT abilities. In PD, attention-processing resources are limited [84]. Therefore, during complex tasks such as BW, which requires high levels of attention, it is difficult to divide already compromised resources between two simultaneous complex tasks (DT and BW). DT requires sustained attention, information processing speed and working memory abilities [85]. Participants of the current study had mild global cognitive dysfunction (MoCA). It is possible that the BWG might have received an overload of complexity during some training tasks, where they followed DT instructions, possibly before being accustomed to BW and thereby compromise information processing improvements. If this was the case, it might explain why the FWG and not the BWG improved their $iTUG^{DT}$ duration.

4.5.5 Limitations and future studies

Findings of this study cannot be generalized as results depend on the tasks used, the cohort included and the medication state of participants. The limitations in the current study that should be considered for future research include firstly, only one walking speed (comfortable, natural pace) was investigated in the current study. As previous studies found different outcomes in mobility parameters [4], a variety of instructional speeds should also be investigated. Secondly, turning strategy used by participants was not investigated. This should be addressed by future studies as it may differ between ST and DT conditions and shed more light on executive impairment during complex tasks, such as turning. Thirdly, turning direction was not monitored and results may not reflect participants' most impaired performance. Future studies should assess turning to both the affected and non-affected sides, as this may influence turning performance [5]. Fourthly, turning performance was only evaluated at one turning angle. Considering that most turns during ADL occur between 76-120° [8], future studies could also include other turning angles that more closely relate to daily life. Lastly, including the number of steps during turning could provide more insight into the turning strategy used. Unfortunately, there was not sufficient data to run an analysis of covariance to see if gender was a covariate or to split data into different PD sub-types. Moreover, this study only included H&Y II-III individuals, making generalizability of results to other PD groups difficult.

4.5.6 Conclusion

Improvements in ST and DT performance illustrates that the ability of PD individuals to learn remains relatively preserved. Given the complexity of and the difficulty PD individuals have with transitional movements, results of the current study shows that the relearning of a well-known task (FW), rather than the learning of a new, complex task (BW), is more beneficial for performance in complex, well-known tasks i.e. postural transitions and turning. Moreover, it is clear that the direction of gait retraining should reflect the direction of the transitional movements.

4.5.7 Acknowledgements

The researchers thank the participants for their time and effort to complete the intervention, Miss EM Atterbury for assisting with the exercise sessions as well as Prof M Kidd for assisting with the statistical analyses. The authors also acknowledge the Department of Sport Science (Stellenbosch University) for support. This publication was supported by Grant Number TTK13070920812 from the National Research Foundation (NRF, South Africa). Its contents are solely the responsibility of the authors, and do not necessarily represent the official views of the NRF.

4.6 References

[1] S.L. Whitney, D.M. Wrisley, G.F. Marchetti, M.A. Gee, M.S. Redfern, J.M. Furman, Clinical measurement of sit-to-stand performance in people with balance disorders: validity of data for the Five-Times-Sit-to-Stand Test., Phys. Ther. 85 (2005) 1034–1045. doi:10.1191/026921598673062266.

[2] P. Chou, S. Lee, Turning de fi cits in people with Parkinson ' s disease, Tzu Chi Med. J. 25 (2013) 200–202. doi:10.1016/j.tcmj.2013.06.003.

[3] A. Nagal, R.K. Singla, Parkinson â€™ s Disease : Diagnosis , Therapeutics & Management Parkinson â€™ s Disease : Diagnosis , Therapeutics & Management, WebmedCentral Pharm. Sci. 3 (2016) WMC003670. http://www.webmedcentral.com/article_view/3670 Subject.

[4] S. Mellone, M. Mancini, L.A. King, F.B. Horak, L. Chiari, The quality of turning in Parkinson ' s disease : a compensatory strategy to prevent postural instability ?, J. Neuroeng. Rehabil. (2016) 1–9. doi:10.1186/s12984-016-0147-4.

[5] F.Y. Cheng, Y.R. Yang, C.J. Wang, Y.R. Wu, S.J. Cheng, H.C. Wang, R.Y. Wang, Factors influencing turning and its relationship with falls in individuals with Parkinson's disease, PLoS One. 9 (2014) 1–6. doi:10.1371/journal.pone.0093572.

[6] L. a King, M. Mancini, K. Priest, A. Salarian, F. Rodrigues-de-Paula, F. Horak, Do clinical scales of balance reflect turning abnormalities in people with Parkinson's disease?, J. Neurol. Phys. Ther. 36 (2012) 25–31. doi:10.1097/NPT.0b013e31824620d1.

[7] M. El-Gohary, S. Pearson, J. McNames, M. Mancini, F. Horak, S. Mellone, L. Chiari, Continuous monitoring of turning in patients with movement disability., Sensors (Basel). 14 (2013) 356–369. doi:10.3390/s140100356.

[8] J. Song, S. Sigward, B. Fisher, G.J. Salem, Altered dynamic postural control during step turning in persons with early-stage Parkinson's disease, Parkinsons. Dis. 2012 (2012). doi:10.1155/2012/386962.

[9] M. Plotnik, N. Giladi, Y. Balash, C. Peretz, J.M. Hausdorff, Is freezing of gait in Parkinson's disease related to asymmetric motor function?, Ann. Neurol. 57 (2005) 656–663. doi:10.1002/ana.20452.

[10] D.S. Peterson, F.B. Horak, Neural Control of Walking in People with Parkinsonism, Physiology. 31 (2016) 95–107. doi:10.1152/physiol.00034.2015.

[11] E. Stack, A. Ashburn, Dysfunctional turning in Parkinson ' s disease, 30 (2008) 1222–1229. doi:10.1080/09638280701829938.

[12] G.M. Earhart, M.J. Falvo, Parkinson disease and exercise, Compr. Physiol. 3 (2013) 833–848. doi:10.1002/cphy.c100047.

[13] C. Curtze, J.G. Nutt, P. Carlson-Kuhta, M. Mancini, F.B. Horak, Levodopa Is a Double-Edged Sword for Balance and Gait in People With Parkinson's Disease, Mov. Disord. 30 (2015) 1361–1370. doi:10.1002/mds.26269.

[14] T. Toole, C.G. Maitland, E. Warren, M.F. Hubmann, L. Panton, The effects of loading and unloading treadmill walking on balance, gait, fall risk, and daily function in Parkinsonism., NeuroRehabilitation. 20 (2005) 307–322.

[15] J.D. Childs, C. Gantt, D. Higgins, J. a Papazis, R. Franklin, T. Metzler, F.B. Underwood, The effect of repeated bouts of backward walking on physiologic efficiency., J. Strength Cond. Res. 16 (2002) 451–455. doi:10.1519/1533-4287(2002)016<0451:TEORBO>2.0.CO;2.

[16] Y. Laufer, Effect of age on characteristics of forward and backward gait at preferred and accelerated walking speed., J. Gerontol. A. Biol. Sci. Med. Sci. 60 (2005) 627–632. doi:10.1093/gerona/60.5.627.

[17] H. Cha, T. Kim, M. Kim, Therapeutic efficacy of walking backward and forward on a slope in normal adults, (2016) 1901–1903. doi:10.1589/jpts.28.1901.

[18] E. Terblanche, C. Page, J. Kroff, R.E. Venter, The effect of backward locomotion training on the body composition and cardiorespiratory fitness of young women, Int. J. Sports Med. 26 (2005) 214–219. doi:10.1055/s-2004-820997.

[19] J.Y. Taipei, M.W. Hospital, L. Yen, C. Hsin, R. Medical, Gait outcomes after additional backward walking training in patients with stroke : a randomized controlled trial, (2005) 264–273.

[20] V.G. DePaul, L.R. Wishart, J. Richardson, T.D. Lee, L. Thabane, Varied overground walking-task practice versus body-weight-supported treadmill training in ambulatory adults within one year of stroke: a randomized controlled trial protocol, BMC Neurol. 11 (2011) 129. doi:10.1186/1471-2377-11-129.

[21] K. Kim, S. Lee, K. Lee, Effects of Progressive Body Weight Support Treadmill Forward and Backward Walking Training on Stroke Patients ' Affected Side Lower Extremity ' s Walking Ability, (2014).

[22] S.M. Michaelsen, A.C. Ovando, F. Romaguera, L. Ada, Effect of backward walking treadmill training on walking capacity after stroke: A randomized clinical trial, Int. J. Stroke. 9 (2014) 529–532. doi:10.1111/ijs.12255.

[23] H.M.Y. El-basatiny, Effect of backward walking training on postural balance in children with hemiparetic cerebral palsy : a randomized controlled study, (2015). doi:10.1177/0269215514547654.

[24] W. Hoogkamer, P. Meyns, J. Duysens, Steps Forward in Understanding Backward Gait : From Basic Circuits to Rehabilitation, 42 (2014).

[25] T.L. McIsaac, E.M. Lamberg, L.M. Muratori, Building a framework for a dual task taxonomy, Biomed Res. Int. 2015 (2015). doi:10.1155/2015/591475.

[26] J.S. Schneider, S. Sendek, C. Yang, Relationship between motor symptoms, cognition, and demographic characteristics in treated mild/moderate Parkinson's disease, PLoS One. 10 (2015) 1–11. doi:10.1371/journal.pone.0123231.

[27] B.R. Bloem, J.M. Hausdorff, J.E. Visser, N. Giladi, Falls and freezing of Gait in Parkinson's disease: A review of two interconnected, episodic phenomena, Mov. Disord. 19 (2004) 871–884. doi:10.1002/mds.20115.

[28] V.E. Kelly, A.J. Eusterbrock, A. Shumway-Cook, A review of dual-task walking deficits in people with Parkinson's disease: Motor and cognitive contributions, mechanisms, and clinical implications, Parkinsons. Dis. 2012 (2012). doi:10.1155/2012/918719.

[29] S. Koch, R.W. Holland, M. Hengstler, A. Van Knippenberg, Body Locomotion as Regulatory Process Stepping Backward Enhances Cognitive Control, 20 (2009) 549–551.

[30] M.M. Hoehn, M.D. Yahr, Parkinsonism : onset , progression , and mortality, 17 (1967). doi:10.1212/WNL.17.5.427.

[31] S. Hoops, S. Nazem, A.D. Siderowf, J.E. Duda, S.X. Xie, M.B. Stern, D. Weintraub, Validity of the MoCA and MMSE in the detection of MCI and dementia in Parkinson disease, Neurology. 73 (2009) 1738–1745. doi:10.1212/WNL.0b013e3181c34b47.

[32] M. Mancini, F.B. Horak, Potential of APDM Mobility Lab for the monitoring of the progression of Parkinson's disease, Expert Rev. Med. Devices. 4440 (2016) 17434440.2016.1153421. doi:10.1586/17434440.2016.1153421.

[33] M.A. Simoes, Feasibility of Wearable Sensors to Determine Gait Parameters, Dep. Mech. Eng. Master of (2011) 108. doi:10.1007/s13398-014-0173-7.2.

[34] F.B. Horak, M. Mancini, Objective biomarkers of balance and gait for Parkinson's disease using body-worn sensors, Mov. Disord. 28 (2013) 1544–1551. doi:10.1002/mds.25684.

[35] L.A. King, A. Salarian, M. Mancini, K.C. Priest, J. Nutt, A. Serdar, J. Wilhelm, J. Schlimgen, M. Smith, F.B. Horak, Exploring outcome measures for exercise intervention in people with Parkinson's disease, Parkinsons. Dis. 2013 (2013). doi:10.1155/2013/572134.

[36] R.P. Duncan, A.L. Leddy, G.M. Earhart, Five Times Sit to Stand Test Performance in Parkinson Disease, Arch. Phys. Med. Rehabil. 92 (2011) 1431–1436. doi:10.1016/j.apmr.2011.04.008.Five.

[37] E.L. Stegemöller, J. Nocera, I. Malaty, M. Shelley, M.S. Okun, C.J. Hass, Timed up and go, cognitive, and quality-of-life correlates in Parkinson's Disease, Arch. Phys. Med. Rehabil. 95 (2014) 649–655. doi:10.1016/j.apmr.2013.10.031.

[38] T. Steffen, M. Seney, Test-retest reliability and minimal detectable change on balance and ambulation tests, the 36-item short-form health survey, and the unified Parkinson disease rating scale in people with parkinsonism., Phys. Ther. 88 (2008) 733–746. doi:10.2522/ptj.20070214.

[39] A. Salarian, F.B. Horak, C. Zampieri, P. Carlson-Kuhta, J.G. Nutt, K. Aminian, ITUG, a sensitive and reliable measure of mobility, IEEE Trans. Neural Syst. Rehabil. Eng. 18 (2010) 303–310. doi:10.1109/TNSRE.2010.2047606.

[40] M. Mancini, K.C. Priest, J.G. Nutt, F.B. Horak, Quantifying freezing of gait in Parkinson's disease during the instrumented timed up and go test., Conf. Proc. ... Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. IEEE Eng. Med. Biol. Soc. Annu. Conf. 2012 (2012) 1198–201. doi:10.1109/EMBC.2012.6346151.

[41] R.L. Fuller, E.P. Van Winkle, K.E. Anderson, A.L. Gruber-Baldini, T. Hill, C. Zampieri, W.J. Weiner, L.M. Shulman, Dual task performance in Parkinson's disease: A sensitive predictor of impairment and disability, Park. Relat. Disord. 19 (2013) 325–328. doi:10.1016/j.parkreldis.2012.11.011.

[42] E.M. Atterbury, Home-based balance training for dynamic balance in independent- living individuals with Parkinson ' s disease, Dr. Diss. Stellenbosch Univ. (2015).

[43] S. Springer, N. Giladi, C. Peretz, G. Yogev, E.S. Simon, J.M. Hausdorff, Dual-tasking effects on gait variability: The role of aging, falls, and executive function, Mov. Disord. 21 (2006) 950–957. doi:10.1002/mds.20848.

[44] M. Plotnik, N. Giladi, Y. Dagan, J.M. Hausdorff, Postural instability and fall risk in Parkinson's disease: Impaired dual tasking, pacing, and bilateral coordination of gait during the "oN" medication state, Exp. Brain Res. 210 (2011) 529–538. doi:10.1007/s00221-011-2551-0.

[45] G. Yogev-Seligmann, N. Giladi, M. Brozgol, J.M. Hausdorff, A training program to improve gait while dual tasking in patients with Parkinson's disease: A pilot study, Arch. Phys. Med. Rehabil. 93 (2012) 176–181. doi:10.1016/j.apmr.2011.06.005.

[46] S. O'Shea, M.E. Morris, R. Iansek, Research Report in People With Parkinson Disease : Effects of Motor Versus Cognitive, J. Am. Phys. Ther. Assoc. 82 (2002) 888–897.

[47] P. Plummer, G. Eskes, Measuring treatment effects on dual-task performance: a framework for research and clinical practice., Front. Hum. Neurosci. 9 (2015) 225. doi:10.3389/fnhum.2015.00225.

[48] C.G. Goetz, S. Fahn, P. Martinez-Martin, W. Poewe, C. Sampaio, G.T. Stebbins, M.B. Stern, B.C. Tilley, R. Dodel, B. Dubois, R. Holloway, J. Jankovic, J. Kulisevsky, A.E. Lang, A. Lees, S. Leurgans, P.A. LeWitt, D. Nyenhuis, C.W. Olanow, O. Rascol, A. Schrag, J.A. Teresi, J.J. Van Hilten, N. LaPelle, Movement disorder society-sponsored revision of the unified Parkinson's disease rating scale (MDS-UPDRS): Process, format, and clinimetric testing plan, Mov. Disord. 22 (2007) 41–47. doi:10.1002/mds.21198.

[49] M. Ganesan, T.N. Sathyaprabha, P.K. Pal, A. Gupta, Partial Body Weight-Supported Treadmill Training in Patients with Parkinson Disease: Impact on Gait and Clinical Manifestation, Arch. Phys. Med. Rehabil. 96 (2015) 1557–1565. doi:10.1016/j.apmr.2015.05.007.

[50] G.T. Stebbins, C.G. Goetz, D.J. Burn, J. Jankovic, T.K. Khoo, B.C. Tilley, How to identify tremor dominant and postural instability/gait difficulty groups with the movement disorder society unified Parkinson's disease rating scale: Comparison with the unified Parkinson's disease rating scale, Mov. Disord. 28 (2013) 668–670. doi:10.1002/mds.25383.

[51] C. Jenkinson, R. Fitzpatrick, V. Peto, R. Greenhall, N. Hyman, The Parkinson's disease questionnaire (PDQ-39): Development and validation of a Parkinson's disease summary index score, Age Ageing. 26 (1997) 353–357. doi:10.1093/ageing/26.5.353.

[52] M. Mancini, M. El-Gohary, S. Pearson, J. Mcnames, H. Schlueter, J.G. Nutt, L.A. King, F.B. Horak, Continuous monitoring of turning in Parkinson's disease: Rehabilitation potential, NeuroRehabilitation. 37 (2015) 3–10. doi:10.3233/NRE-151236.

[53] A. Nieuwboer, G. Kwakkel, L. Rochester, D. Jones, E. van Wegen, a M. Willems, F. Chavret, V. Hetherington, K. Baker, I. Lim, Cueing training in the home improves gait-related mobility in Parkinson's disease: the RESCUE trial., J. Neurol. Neurosurg. Psychiatry. 78 (2007) 134–140. doi:10.1136/jnnp.200X.097923.

[54] G. Brichetto, E. Pelosin, R. Marchese, G. Abbruzzese, Evaluation of physical therapy in parkinsonian patients with freezing of gait : a pilot study, Clin. Rehabil. 20 (2006) 31–35. doi:10.1191/0269215506cr913oa.

[55] S.G. Brauer, M.H. Woollacott, R. Lamont, S. Clewett, J. O'Sullivan, P. Silburn, G.D. Mellick, M.E. Morris, Single and dual task gait training in people with Parkinson's disease: a protocol for a randomised controlled trial., BMC Neurol. 11 (2011) 90. doi:10.1186/1471-2377-11-90.

[56] C. Peters, M. Currin, S. Tyson, A. Rogers, S. Healy, S. McPhail, S.G. Brauer, K. Heathcote, T. Comans, A randomized controlled trial of an enhanced interdisciplinary community based group program for people with Parkinson's disease: study rationale and protocol., Neurol. Int. 4 (2012) e3. doi:10.4081/ni.2012.e3.

[57] D.S. Peterson, M. Plotnik, J.M. Hausdorff, G.M. Earhart, Evidence for a relationship between bilateral coordination during complex gait tasks and freezing of gait in Parkinson's disease, Park. Relat. Disord. 18 (2012) 1022–1026. doi:10.1016/j.parkreldis.2012.05.019.

[58] S. Keus, M. Munneke, M. Graziano, J. Paltamaa, E. Pelosin, J. Domingos, B. Ramaswamy, J. Prins, C. Struiksma, L. Rochester, A. Nieuwboer, B. Bloem, European Physiotherapy Guideline for Parkinson ' s Disease Developed with twenty European professional associations, KNGF/ParkinsonNet, the Netherlands. 1 (2014) 32.

[59] X. Shen, M.K.Y. Mak, Balance and Gait Training With Augmented Feedback Improves Balance Confidence in People With Parkinson's Disease: A Randomized Controlled Trial., Neurorehabil. Neural Repair. 28 (2014) 524–535. doi:10.1177/1545968313517752.

[60] R.G. Cohen, V.S. Gurfinkel, E. Kwak, A.C. Warden, F.B. Horak, Lighten Up: Specific Postural Instructions Affect Axial Rigidity and Step Initiation in Patients With Parkinson's Disease, Neurorehabil. Neural Repair. 29 (2015) 878–888. doi:10.1177/1545968315570323.

[61] Â. Fernandes, N. Rocha, R. Santos, J.M.R.S. Tavares, Effects of dual-task training on balance and executive functions in Parkinson's disease: A pilot study., Somatosens. Mot. Res. 220 (2015) 1–6. doi:10.3109/08990220.2014.1002605.

[62] G. Abbruzzese, R. Marchese, L. Avanzino, E. Pelosin, Rehabilitation for Parkinson's disease: Current outlook and future challenges, Park. Relat. Disord. 22 (2016) S60–S64. doi:10.1016/j.parkreldis.2015.09.005.

[63] G.M. Petzinger, B.E. Fisher, S. McEwen, J.A. Beeler, J.P. Walsh, M.W. Jakowec, Exercise-enhanced neuroplasticity targeting motor and cognitive circuitry in Parkinson's disease, Lancet Neurol. 12 (2013) 716–726. doi:10.1016/S1474-4422(13)70123-6.

[64] T. Gregory, K. Welman, Somatosensory training for postural control in independent-living individuals with Parkinson's disease, Dr. Diss. Stellenbosch Univ. (2015).

[65] W. Thalheimer, S. Cook, How to calculate effect sizes from published research: A simplified methodology, Work. Res. (2002) 1–9. doi:10.1113/jphysiol.2004.078915.

[66] G. Alves, E.B. Forsaa, K.F. Pedersen, M. Dreetz Gjerstad, J.P. Larsen, Epidemiology of Parkinson's disease, J. Neurol. 255 (2008) 18–32. doi:10.1007/s00415-008-5004-3.

[67] J. Dufek, A. House, B. Mangus, G. Melcher, J. Mercer, Backward Walking: A Possible Active Exercise for Low Back Pain Reduction and Enhanced Function in Athletes, J. Exerc. Physiol. Online. 14 (2011) 17–26. http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=65237695&site=ehost-live.

[68] P.C. Gordon, J. Barbosa, L.M. Medeiros, L.F.R. Oliveira, A.M. Neto, D.K. Amado, M.S.G. Rocha, H. Santa, M. São, P. Brazil, Instrumented quantitative study of movement and gait in Parkinson ' s disease clinical subtypes, (2016) 27–28. doi:10.13140/RG.2.1.1290.7125.

[69] N. Millor, P. Lecumberri, M. Gomez, A. Martìnez-Ramirez, M. Izquierdo, Kinematic parameters to evaluate functional performance of sit-to-stand and stand-to-sit transitions using motion sensor devices: A systematic review, IEEE Trans. Neural Syst. Rehabil. Eng. 22 (2014) 926–936. doi:10.1109/TNSRE.2014.2331895.

[70] E.P. Doheny, C.W. Fan, T. Foran, B.R. Greene, C. Cunningham, R.A. Kenny, An instrumented sit-to-stand test used to examine differences between older fallers and non-fallers, Proc. Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. EMBS. (2011) 3063–3066. doi:10.1109/IEMBS.2011.6090837.

[71] T. Bhatt, F. Yang, M.K.Y. Mak, C.W.-Y. Hui-Chan, Y.-C. Pai, Effect of externally cued training on dynamic stability control during the sit-to-stand task in people with Parkinson disease., Phys. Ther. 93 (2013) 492–503. doi:10.2522/ptj.20100423.

[72] N.E. Allen, C.G. Canning, C. Sherrington, S.R. Lord, M.D. Latt, J.C.T. Close, S.D. O'Rourke, S.M. Murray, V.S.C. Fung, The effects of an exercise program on fall risk factors in people with Parkinson's disease: A randomized controlled trial, Mov. Disord. 25 (2010) 1217–1225. doi:10.1002/mds.23082.

[73] N. Toosizadeh, J. Mohler, H. Lei, S. Parvaneh, S. Sherman, B. Najafi, Motor performance assessment in Parkinson's disease: Association between objective in-clinic, objective in-home, and subjective/semi-objective measures, PLoS One. 10 (2015) 1–15. doi:10.1371/journal.pone.0124763.

[74] M. Schenkman, D.A. Hall, A.E. Barón, R.S. Schwartz, P. Mettler, W.M. Kohrt, M. Schenkman, D.A. Hall, A.E. Baro, R.S. Schwartz, P. Mettler, W.M. Kohrt, Research Report Exercise for People in Early- or Mid- Stage Parkinson Disease : A 16-Month Randomized Controlled Trial, J. Am. Phys. Ther. Assoc. 92 (2012) 1395–1411. doi:10.2522/ptj.20110472.

[75] M.R. Adame, A. Al-Jawad, M. Romanovas, M. a. Hobert, W. Maetzler, K. Möller, Y. Manoli, TUG Test Instrumentation for Parkinson's disease patients using Inertial Sensors and Dynamic Time Warping, Biomed. Eng. / Biomed. Tech. 57 (2012) 5–9. doi:10.1515/bmt-2012-4426.

[76] L.M. Melo Santiago, D.A. Oliveira, L.G.L. Macedo Ferreira, H.Y. Brito Pinto, A.P. Spaniol, L.C. Lucena Trigueiro, T.S. Ribeiro, A.V.C. Sousa, M.E.P. Piemonte, A.R.R. Lindquist, L.M. de M. Santiago, D.A. De Oliveira, L.G.L. de Macedo Ferreira, H.Y. De Brito Pinto, A.P. Spaniol, L.C. De Lucena Trigueiro, T.S. Ribeiro, A.V.C. De Sousa, M.E.P. Piemonte, A.R.R. Lindquist, L.M. De Melo Santiago, D.A. De Oliveira, L.G.L. De Macêdo Ferreira, H.Y. De Brito Pinto, A.P. Spaniol, L.C. De Lucena Trigueiro, T.S. Ribeiro, A.V.C. De Sousa, M.E.P. Piemonte, A.R.R. Lindquist, Immediate effects of adding mental practice to physical practice on the gait of individuals with Parkinson's disease: Randomized clinical trial, NeuroRehabilitation. 37 (2015) 263–271. doi:10.3233/NRE-151259.

[77] C. Curtze, J.G. Nutt, P. Carlson-Kuhta, M. Mancini, F.B. Horak, Objective Gait and Balance Impairments Relate to Balance Confidence and Perceived Mobility in People With Parkinson's Disease., Phys. Ther. (2016) ptj.20150662-. doi:10.2522/ptj.20150662.

[78] A.A. Moustafa, S. Chakravarthy, J.R. Phillips, A. Gupta, S. Keri, B. Polner, M.J. Frank, M. Jahanshahi, Motor symptoms in Parkinson's disease: A unified framework, Neurosci. Biobehav. Rev. 68 (2016) 727–740. doi:10.1016/j.neubiorev.2016.07.010.

[79] S. Hulbert, A. Ashburn, L. Robert, G. Verheyden, A narrative review of turning deficits in people with Parkinson's disease, Disabil. Rehabil. 37 (2015) 1382–1389. doi:10.3109/09638288.2014.961661.

[80] K. Smulders, M.L. Dale, P. Carlson-kuhta, J.G. Nutt, F.B. Horak, Parkinsonism and Related Disorders Pharmacological treatment in Parkinson â€™ s disease : Effects on gait, Park. Relat. Disord. (2016). doi:10.1016/j.parkreldis.2016.07.006.

[81] M. Tramontano, S. Bonnì, A. Martino Cinnera, F. Marchetti, C. Caltagirone, G. Koch, A. Peppe, Blindfolded Balance Training in Patients with Parkinson's Disease: A Sensory-Motor Strategy to Improve the Gait, Parkinsons. Dis. 2016 (2016). doi:10.1155/2016/7536862.

[82] N. Toosizadeh, J. Mohler, H. Lei, S. Parvaneh, S. Sherman, B. Najafi, Motor performance assessment in Parkinson's disease: Association between objective in-clinic, objective in-home, and subjective/semi-objective measures, PLoS One. 10 (2015) 1–15. doi:10.1371/journal.pone.0124763.

[83] M. Elshehabi, K.S. Maier, S.E. Hasmann, S. Nussbaum, H. Herbst, T. Heger, D. Berg, M.A. Hobert, W. Maetzler, Limited effect of dopaminergic medication on straight walking and turning in early-to-moderate parkinson's disease during single and dual tasking, Front. Aging Neurosci. 8 (2016). doi:10.3389/fnagi.2016.00004.

[84] G. Ullmann, H.G. Williams, The relationships among gait and mobility under single and dual task conditions in community-dwelling older adults, Aging Clin. Exp. Res. 23 (2011) 400–405. doi:10.3275/7269.

[85] P.F. Tang, H.J. Yang, Y.C. Peng, H.Y. Chen, Motor dual-task Timed Up & Go test better identifies prefrailty individuals than single-task Timed Up & Go test, Geriatr. Gerontol. Int. 15 (2015) 204–210. doi:10.1111/ggi.12258.

CHAPTER 5: ARTICLE 3

Eight-weeks forward and backward over ground gait retraining for dual task interference on gait in early Parkinson's disease: a randomized controlled trial

5.1 Abstract

Introduction: Executive dysfunction in Parkinson's disease (PD) highly affects their dual task (DT) abilities. Training in complex, novel tasks may induce enhanced cortical activity for movement preparation that is beyond training in automatic tasks. Therefore, this study aims to compare the effect of an eight-week forward (FW) and backwards (BW) gait retraining program on DT interference in PD individuals. **Methods:** Concealed, simple randomization was used to divide participants between two exercising groups. Groups performed a 24-session (3x/week for 8 weeks) over ground gait retraining program in opposite directions. The FW group (FWG) included 14 participants (aged: 70±11 years; Hoehn and Yahr (H&Y) stage: 2.7±0.5; disease duration: 7±6 years) and was compared to 15 participants of similar age (72±6 years), H&Y stage (2.7±0.9) and disease duration (5±3 years) in the BW group (BWG). Baseline measures included six-minute-walk-distance, balance confidence and freezing status. The primary outcome variables included selected gait variables during a 10m-instrumented-walk-test (i10mWT) under single task and DT (cognitive, arrhythmic) conditions to calculate the percentage DT interference. Secondary outcome measures were experiences of daily living (Unified Parkinson's Disease Rating scale (UPDRS) II), global cognition (Montreal Cognitive Assessment) and depressive mood (Patient Health Questionnaire-9). **Results:** Improved DT interference was reported in the FWG for stride length ($p=0.02$; $d=0.67$) as well as in the BWG for double support phase (DS) variability ($p=0.05$; $d=0.57$). The BWG also increased DT interference for %DS ($p=0.05$; $d=0.45$) and swing time gait asymmetry ($p=0.02$; $d=0.61$). Additionally, the FWG improved their UPDRS II scores ($p=0.03$, $d=0.44$). **Conclusion:** Under DT conditions, the BWG decreased stability in compensation to fear of falling, but improved control over the walking pattern. In contrast to the BWG, the FWG improved automaticity of gait control under DT conditions.

Key Words: Gait retraining; Parkinson's disease; Retrowalking; Rehabilitation; Dual task interferance

5.2 Introduction

The most disabling clinical manifestation of Parkinson's disease (PD) is gait impairment [1]. As up to 50% of PD falls occur while walking, the effect of gait dysfunction on overall mobility and quality of life (QoL) is clear. Conversely, reduced QoL is related to balance and gait impairments in PD. Non-motor symptoms, such as cognitive decline, affects the performance of regular daily activities – especially those that require the simultaneous performance of cognitive and motor tasks [2]. The ability to perform a secondary task while walking is highly advantageous for independence, especially as it allows people to monitor the environment and avoid possible balance threats. Unfortunately, PD gait impairments are exacerbated during such dual-task (DT) situations [3]. Previously, walking was seen as an automatic task. However, Hausdorff et al. (2005) suggested that walking in real life setting, is a DT. For example, during most daily situations, one would walk and talk or recite a grocery list or observe the environment while moving about. Hence, rehabilitative strategies should focus on improving DT abilities of PD individuals.

It has been shown that intrinsic, pathophysiological factors predispose PD individuals to a high risk of falling. These factors mostly relate to impaired mobility due to gait difficulties, cognitive decline and other disease-related ailments. Falls are also common with DT walking as PD individuals struggle to divide attention in order to perform all the tasks equally well [5]. Moreover, Koch et al. (2009) found that stepping backward can be an avoidance behaviour towards aversive situations and therefore require increased cognitive control relative to stepping forward. This suggests that training BW may improve executive functioning beyond what might be possible with FW to thereby enhance DT abilities and decrease fall risk.

A variety of cognitive impairments, that are associated with PD, contribute to DT gait deficits. These include executive function, attention and visuospatial impairments [2]. With disease progression, the severity and range of cognitive impairments increase, which may reflect the involvement of cortical structures in the disease [7]. The most common cognitive impairment in PD is executive dysfunction [1].

Depending on the type of cognitive impairment, the strategies used to compensate for gait irregularities may be limited. Executive functioning limits PD individuals' ability to safely prioritize tasks during DT. The secondary task is often prioritized above walking, consequently increasing their fall risk. A possible reasons for performance deterioration is a flexible, but limited capacity to process information, where DT-interference occur as the two tasks compete for limited resources. At the same time, the processing of a secondary task is temporarily

postponed while the primary task is completed, resulting in performance decrements of the secondary task [2]. More specifically, one task is controlled by the frontal cortical regions under conscious control, and the other is controlled by the defective basal ganglia [8]. These mechanisms are reflected as decreased movement automaticity, which is normally controlled by the basal ganglia. PD individuals increasingly rely on cognitive resources for movement control, even under minimally demanding circumstances. Consequently, strategies to restore movement automaticity in PD may also restore DT abilities, and vice versa [2].

PD is characterised by disrupted basal ganglia-supplementary motor area (SMA) interaction, where the SMA becomes inhibited as the basal ganglia runs movement sequences to completion. This only occurs with automatic movements. With complex, novel tasks, this loop is bypassed to enhance movement preparation for each sequence. Training that utilizes high levels of attention, especially those that require conscious focus on gait, results in similar findings than visual cue training as they make use of similar mechanisms that bypass the basal ganglia [9]. It is possible that backwards walking (BW), which is a complex and novel task, may utilize a similar bypass mechanism. According to Petzinger et al. (2013), training under DT conditions that relate to daily life may enhance the transfer of the skill to such day-to-day situations. It is possible that training in a complex task such as BW, may induce cortical-subcortical network changes in favour of improved executive control of mobility, even more so when a DT is added. Moreover, due to its complexity, eccentric training, such as BW, allows greater cortical activity for movement preparation and executive function than concentric tasks, making it a feasible option to investigate in individuals with PD who have difficulty in these tasks [11].

Hackney and Earhart (2011) was the first to investigate the effects of DT during BW in PD. Both the PD and control groups were instructed to perform a secondary (cognitive) task during forward walking (FW) and BW, which negatively influenced their mobility. Compared to FW as well as controls, individuals with PD performed the cognitive task at a slower rate and showed greater decrements in BW gait parameters when the secondary, cognitive task was added. This indicates that individuals who suffer from motor deficits, cognitive impairment or both have difficulty regulating gait and coordinating symmetric leg movements, where the impaired automaticity is reflected even more during DT walking (Hackney & Earhart, 2011).

Given these points, it was assumed that the BWG constantly utilized more cognitive resources than the FWG, during both ST and DT training. From this it can be proposed that exercise that requires high levels of concentration could create a better environment for neuroplasticity which might induce more physical and cognitive benefits, than exercise with a low cognitive load, which may especially be useful for neurological rehabilitation. To the researchers' knowledge,

over ground backward and forward gait retraining has not yet been used to investigate DT abilities in PD.

Therefore, the aim of this study was to compare an eight-week over ground backward to a forward gait retraining program on DT abilities of individuals with mild to moderate PD. The primary outcome measures were selected gait measures under both single-task (ST) and DT conditions. Secondary outcome measures included disease severity (UPDRS III), experiences of daily living (UPDRS II), global cognition (MoCA) and depressive mood (PHQ-9).

5.3 Methods

5.3.1 Study design

This randomized controlled study followed a staggered design in three different locations in the Western Cape (South Africa) at four week intervals between April and August 2016. An uninvolved, offsite individual was used to divide participants from each location into two groups, by means of simple randomization in a 1:1 ratio. The study consisted of an eight-week gait retraining intervention and had an experimental group who performed training tasks in the reverse direction (BWG) and a control group who performed training tasks in the forward direction (FWG). The study design is outlined in *Figure 5.1*.

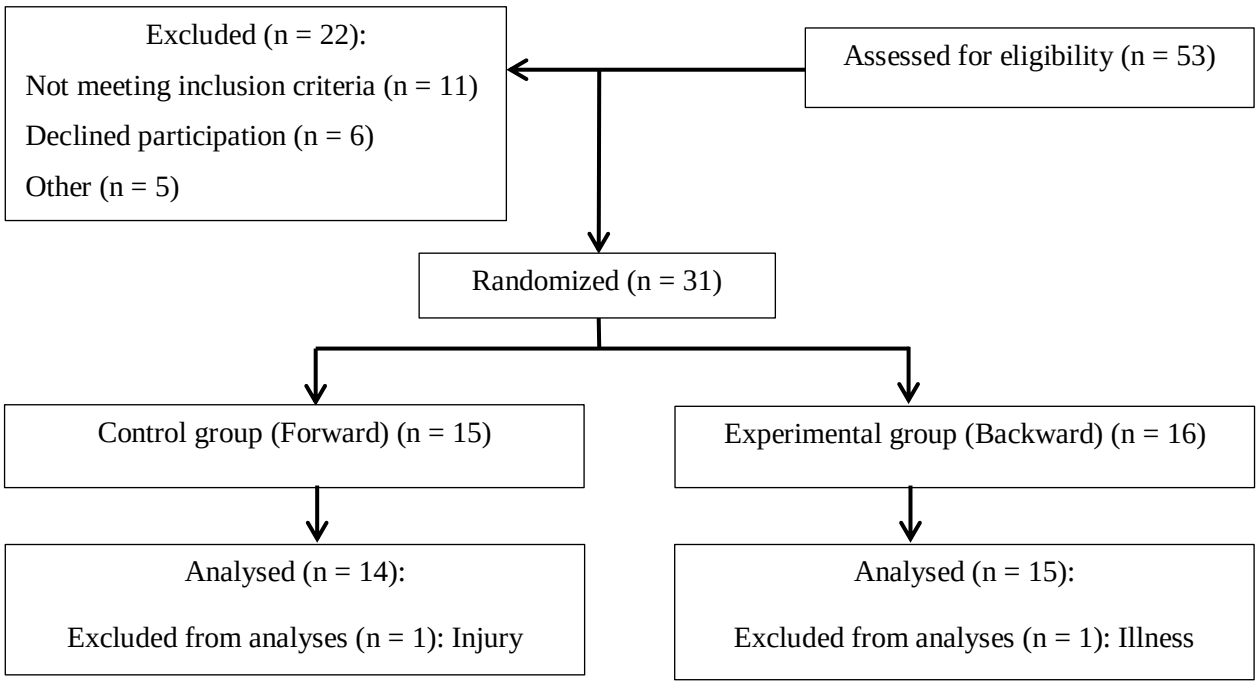


Figure 5.1 Flow diagram of study design

5.3.2 Participants

Possible participants were recruited through advertisement in the local paper, on local radio stations and at PD support groups. Selected gait parameters during single task (ST) and DT conditions were examined in 29 subjects with PD before and after the intervention. Fourteen PD individuals (70.0±6.5 years, 29% women) in the FWG and fifteen PD individuals (72.0±6.0 years, 40% women) in the BWG participated. All participants had mild to moderate PD (Hoehn &Yahr 2–3, [12]). PD participants with other causes of mobility impairments (including recent injury and neurological, cardiovascular or musculoskeletal problems), who could not ambulate independently and who changed their medication over the study period, were excluded. *Table 5.1* outlines descriptive characteristics of the participants. All participants gave informed consent according to the Declaration of Helsinki, and the Institutional Review Board of Stellenbosch University (S16-01-004, Appendix M) approved the study. Due to the study design, it was difficult to completely blind the participants to the main aim of the study. However, participants were blinded to the outcome measures until after completion of the intervention.

5.3.3 Evaluations

Outcome measures were assessed before and after the eight-week exercise intervention at a similar time of the day, in the on-state of levodopa (average time of 3.1±1.7 and 2.9±1.9 hours since taking previous medication at pre- and post-test, respectively), with the same equipment, by the primary researcher who is a qualified clinical exercise therapist (Biokineticist). The primary researcher's intra-rater intraclass correlation coefficients (ICC) ranged from 0.89–0.99 (p=0.58–0.15). Participants were instructed to wear the same, appropriate footwear during both evaluation sessions. Testing ranged between 45-90 minutes per visit.

For descriptive purposes, functional capacity by means of a Six-minute-walk-test (6MWT), balance confidence via the Activity-specific Balance Confidence (ABC) scale and freezing status via the Freezing of Gait questionnaire (FOG) were determined at baseline before outcome measures were assessed (*Table 5.1*). To obtain the primary outcome variables, participants completed a 10m-instrumented-walk-test (i10mWT) under both ST and DT conditions. For the secondary outcome variables, the Movement Disorders Society Unified Parkinson's Disease Rating scale (MDS-UPDRS) part II, Montreal Cognitive Assessment (MoCA) and Patient Health Questionnaire 9 (PHQ-9).

Table 5.1 *Participant descriptive characteristics. Raw values are summarized as mean ± standard deviation (95% confidence interval), except where indicated otherwise*

n	Age (years) / Gender	BMI (kg/m^2)	Disease Duration (years)	H&Y	PD Sub-Type	FOG-Q	F / NF	ABC Scale	6MWT (m)
1	53 / M	32.71	16	3	PIGD	19	F	35	312
2	70 / M	30.60	17	3	PIGD	11	F	55	170
3	76 / M	26.93	4	3	PIGD	9	F	74	246
4	71 / M	27.74	3	3	PIGD	7	NF	64	264
5	73 / M	26.00	8	3	PIGD	10	F	56	306
6	45 / W	20.15	1	2	TD	12	F	36	509
7	70 / M	23.59	10	2	TD	4	NF	94	440
8	80 / W	27.82	1	3	PIGD	12	F	28	291
9	60 / W	24.99	20	2	I	7	F	96	465
10	80 / M	23.94	3	3	TD	4	NF	74	266
11	63 / M	28.69	5	3	PIGD	15	F	55	272
12	86 / W	23.05	1	2	TD	3	F	89	341
13	76 / M	35.56	6	3	PIGD	14	F	56	69
14	76 / M	25.48	6	3	PIGD	6	F	93	317
	70 ± 11 (6.48)	27.0 ± 4.1 (2.34)	7 ± 6 (3.63)	2.7 ± 0.5 (0.27)		9.5 ± 4.7 (2.70)		64.6 ± 22.7 (13.11)	305 ± 114 (65.80)
1	56 / M	26.78	6	3	I	13	F	56	350
2	78 / M	27.58	3	3	TD	11	F	75	339
3	69 / W	20.97	1	3	PIGD	9	F	35	332
4	76 / M	28.70	6	3	PIGD	14	F	54	105
5	73 / M	22.11	11	3	PIGD	8	F	94	291
6	74 / M	30.90	3	3	PIGD	4	NF	84	387
7	79 / M	23.90	2	2	I	1	NF	94	395
8	71 / M	28.93	8	3	PIGD	20	F	36	240
9	77 / M	27.45	5	2	TD	1	NF	95	439
10	67 / W	34.19	10	3	TD	9	F	29	167
11	76 / W	20.90	2	2	TD	0	F	90	307
12	76 / F	17.25	2	2	TD	0	NF	82	330
13	73 / F	39.61	3	2	PIGD	18	F	24	236
14	72 / M	32.91	3	3	TD	3	NF	87	399
15	64 / F	21.37	7	3	TD	6	F	75	330
	72 ± 6 (3.37)	26.9 ± 6.0 (3.32)	5 ± 3 (1.72)	2.7 ± 0.9 (0.27)		7.8 ± 6.5 (0.42)		67.3 ± 25.9 (14.36)	310 ± 91 (50.12)
p	0.53/ 0.52	0.98	0.21	0.79	0.42	0.42	0.47	0.75	0.90

Abbreviations: M = male; F = women; BMI = Body Mass Index; H&Y = Hoehn and Yahr; PIGD = Postural instability and gait difficulty; TD = Tremor dominant; I = Indeterminate; FOG-Q = Freezing of Gait Questionnaire; F = Freezers; NF = Non-freezers; ABC = Activity Specific Balance Confidence; 6MWT = Six-minute Walk Test; LED = Levodopa Equivalent Dosage

a) Descriptive variables

Motor symptoms severity was assessed by means of Part III of the MDS-UPDRS III (r=0.96 [13]. Derived from UPDRS assessments, participants were categorized as being tremor dominant (TD) or having postural instability or gait difficulty (PIGD) and the remaining individuals were categorized as indeterminate [14]. The 6MWT was used to assess functional capacity [15] and to obtain valid and reliable (ICC=0.96) information on mobility impairments in PD [16]. Balance

confidence was assessed with the ABC scale, which is a valid (r= –0.66) and reliable (ICC=0.94) measure of fall risk in PD [15]. The FOG-Q a valid and reliable (r=0.84) questionnaire to assess the effect of gait difficulties and freezing status on independence [16].

b) Primary outcomes variables

For the i10mWT, the Mobility Lab system was used (APDM®, Beta version, Portland, OR, USA) to track spatiotemporal parameters (2.40-2.48GHz [17]). This inertial system makes use of six Opal sensors (composed of an accelerometer, gyroscope and magnetometer) that is 48.4mm x 36.1mm x 13.4mm in dimensions. APDM's Mobility Lab tracks movement performance in PD and yield comparable results to motion analysis systems such as Vicon (Vicon, Oxford Metrics

Group, Oxford, UK [18]). Results for gait variables have shown to be sensitive, reliable (r=0.89, p=0.58) and valid (ICC: 0.74-0.87) to assess mobility in PD during prescribed motor tasks [15,17,19]. After completion of a test, selected spatiotemporal variables are exported into Excel 2010 (Microsoft®, Microsoft Corporation, USA) for further analyses.

Instructions of the i10mWT required participants to walk at a comfortable and self-selected pace for i10m and then stop when they crossed a line on the floor without turning around. The i10mWT was demonstrated to participants and after checking for understanding, without a familiarization attempt, they performed two trials, with 30-60 seconds rest in-between and the average measures were used [9]. All basic spatiotemporal gait parameters were recorded under ST and DT conditions. For the purpose of this study, i10mWT duration, stride velocity (SV) normalized to stature, gait cycle (GC) time, cadence, stride length (SL) and double support phase (DS) is reported. Furthermore, coefficient of variance of these variables (CoV=[SD÷mean]x100) as well as swing time and step duration gait asymmetry (GA) was calculated [20].

Considering that, in early PD, mobility difficulties are sometimes not demonstrated under ST conditions, Fuller et al. (2013) and Atterbury (2016) found that impairments become evident under DT conditions. Therefore, it is suggested that PD mobility impairments should be tested in an ecological valid way, i.e. under DT conditions. Consequently, evaluating PD individuals while DT gives an better indication of the underlining mobility impairments and fall risk [23]. Therefore, for the DT trials, participants were required to count backwards aloud by three's from a randomly selected number (100, 200, 300…1000) [24,25]. At post-testing, the number with which participants subtracted by, was also randomized (2, 3, 4…10) to avoid the possibility of the learning effect. Previous research reports that a verbal-cognitive secondary task causes gait interference in PD individuals [26]. The interference of the secondary task on gait performance

(the proportion difference between ST and DT performance, or DT cost; %DTC) was calculated as shown in Appendix L [27].

c) Secondary outcome variables

Disease related motor experiences of daily living was assessed by means of the MDS-UPDRS Part II (Appendix J), which has been reported as a valid and reliable (r=0.92) tool [13,28]. Global cognition was assessed with MoCA – a standardized, valid and reliable (ICC=0.79) neuropsychological screening tool for all levels of cognition in PD, where a score of <17 indicates severe cognitive impairment [29,30]. At baseline, version 7.1 was used for all participants. To avoid the learning effect, versions 7.2 and 7.3 was randomized for participants at post-testing. Depressive mood of participants were assessed with the PHQ-9, which is a reliable and valid (ICC=0.63) measure in PD [31,32].

5.3.4 Training intervention

The current intervention made use of an eight-week indoor, over ground forward or backward gait retraining program, where participants performed three weekly exercise sessions. Participants had an average attendance rate of 91.2±9.2% and 92.2±7.9% for the FWG and BWG, respectively. Each session was 45-60 minutes long and mostly included gait exercises, but also stretching and other activities. There were three set versions for warm-up and cool-down sequences, which were alternated between sessions. Abbruzzese et al. (2016) recently suggested that rehabilitation should be complex and include functional tasks to realistically mirror real life. Thus, more cognitive resources are recruited to thereby also train executive control of mobility [10]. A summary of the training program is provided in Appendix A.

The training program had weekly objectives that focussed on: 1) familiarization of proper posture and gait task (foot strike and push off); 2) familiarization of increased step length; 3) overall over ground walking technique (coordination and gait initiation); 4) velocity, cadence and distance walking; 5) directional change abilities; 6) obstacle negotiation; 7) locomotion as it relates to daily activities and 8) circuit training [8,34–39].

Both the control (FWG) and experimental (BWG) groups followed the same outline during the intervention. The gait tasks included walking while focusing on different gait-related aspects while utilizing different types of cues. Exercises were progressed by combining gait tasks, utilizing different obstacles and by adding motor and cognitive tasks. Dual task activities were included in the training program as progressions. Both groups performed the same type of DT,

which were different than what was used during testing. At the end of each session, participants were asked to give a Rating of Perceived Exertion (RPE) by using the 0-10 Borg Scale.

5.3.5 Statistical analysis

Based on data (SL, gait speed, cadence) from a preliminary study done by the same laboratory, a sample size of 40 participants was recommended by a statistician to reach a statistical power of 80% (α=0.05) and an estimated moderate effect size (d=0.60) [22,40]. Results from participants who had >75% attendance were included for analyses.

All data were found to be reasonably normally distributed according to results from Shapiro-Wilks tests and QQ plots. Statistica® software (version 13, StatSoft, Inc., Tulsa, USA) for Windows was used to perform ANOVA's and post hoc analysis at a 5% significance level. A mixed model repeated measures ANOVA with two fixed effects (group and time), where participants were included as a random effect, was used. The group-time interaction effect was used to assess changes from pre- to post-testing for both groups. Chi^2 tests were performed on categorical measures. For post hoc analysis, Fisher exact LSD calculations were used to evaluate between group and over-time significance.

Descriptive and clinical characteristics between the two exercise groups were summarized by using Excel 2010 (Microsoft®). Descriptive variables and mobility parameters were presented as means and standard deviations with 95% confidence limits (CI) or number of observations (f) and percentages for qualitative data. To determine possible clinical significant differences, Cohen's effect sizes were calculated to differentiate between a small (0.15), medium (0.40) and large (0.75) effect [41].

5.4 Results

A summary of main- and interaction-effects of descriptive and outcome variables are outlined in Appendix O. The twenty-nine participants who completed the intervention (*Figure 5.1*) had a disease duration of 6.0±5.0 years (p=0.21; d=0.44) and severity (UPDRS III score) of 35.6±9.5 (p=0.27; d=0.43) at baseline. Participants had similar ABC scores and functional capacity prior to the intervention (p=0.75, d= 0.11 and p=0.90, d=0.05, respectively). For the FOG-Q, 9.5±4.7 (3-19) and 7.8±6.5 (0-20) was scored by the respective FWG and BWG (p=0.42, d=0.31). In the FWG, 78.6% were classified as freezers compared to 66.7% in the BWG (p=0.47). More details on descriptive variables are outline in *Table 5.2*.

Primary outcome variables over time and between groups are outlined in *Table 5.3*, expressed as dual task cost. Considering that all variables were influenced by the DT (indicated by negative values), the absolute values were used for the results.

GROUPxTIME interaction effects was observed for stride velocity (p=0.02), %DS (p=0.04), %DS CoV (p=0.05), swing time GA (p=0.03) and SL (p=0.05), but not for any of the other variables (p>0.05). Post hoc analysis showed improved interference for %DS CoV (p=0.05) in the BWG; however, interference for %DS and swing time GA worsened over time with 46.5% (p=0.05) and 140.5% (p=0.02), respectively. Also, %DTC for SL was improved by 59.7% in the FWG (p=0.02).

A main TIME-effect was observed for UPDRS II scores (p=0.04), without a GROUPxTIME effect (p=0.28). Post hoc investigations showed that the 18.0% improvement in the FWG (16.3±7.3 to 14±8.4) were significant (p=0.03, *d*=0.44).

Global cognition did not show a GROUPxTIME effect (p=0.32) with MoCA.

For depression scores on the PHQ-9 a TIME-effect (p=0.04) without a GROUPxTIME effect (p=0.81) was observed. Scores at baseline were 6.7±5.8 and 7.0±5.9, which improved to 5.2±3.3 and 5.1±5.2 for the FWG (p=0.19, *d*=0.33) and BWG (p=0.09, *d*=0.35), respectively; however no significant results were observed with post hoc analysis.

Considering the difficulty of the two training methods, it becomes clear that the FWG consistently had higher RPE. Compared to BW, FW is a well-known task. Keeping in mind that PD individuals have balance impairments, one can deduct that the FWG were able to exercise at higher intensities while the BWG could not have increased the intensity as much, as their training task was novel and much more complex. Taken together, even though BW was more difficult, it did not yield higher ratings of perceived exertion. Firstly, this indicates that the BWG created safe environments for themselves that did not require exertion. Secondly, the lower levels of exertion might be the reason for limited neural improvements, as it is well known that neural changes require sufficient intensities.

Table 5.2 *Percentage dual task interference of selected gait variables where higher values indicate deterioration and lower values indicate improvement. Values are mean±SD (95% Confidence Interval)*

Variable	FWG (n = 14)	BWG (n =15)	p; Effect size
Total duration			
Pre	69.2±101.3 (58.5)	101.7±281.8 (156.0)	[1]p = 0.58; *d* = 0.16[S]
Post	33.6±31.8 (18.4)	48.0±40.9 (22.6)	[2]p = 0.80; *d* = 0.41[M]
	[3]p = 0.52; *d* = 0.49[M]	[4]p = 0.32; *d* = 0.28[S]	
Stride velocity			
Pre	25.9±16.0 (9.7)	21.6±9.5 (5.5)	[1]p = 0.39; *d* = 0.34[S]
Post	20.6±14.2 (8.2)	26.8±13.9 (7.7)	[2]p = 0.23; *d* = 0.46[M]
	[3]p = 0.06^; *d* = 0.36[S]	[4]p = 0.12; *d* = 0.45[M]	
Stride velocity CoV			
Pre	60.5±62.8 (38.0)	39.5±45.8 (26.4)	[1]p = 0.42; *d* = 0.4[M]
Post	27.0±50.4 (29.1)	48.0±104.7 (58.0)	[2]p = 0.43; *d* = 0.26[S]
	[3]p = 0.19; *d* = 0.61[M]	[4]p = 0.70; *d* = 0.11[N]	
Gait cycle time			
Pre	17.1±22.2 (13.4)	12.1±6.2 (3.6)	[1]p = 0.38; *d* = 0.35[S]
Post	15.9±10.8 (6.2)	19.3±17.6 (9.7)	[2]p = 0.56; *d* = 0.24[S]
	[3]p = 0.71; *d* = 0.07[N]	[4]p = 0.10; *d* = 0.56[M]	
Gait cycle time CoV			
Pre	116.9±111.1 (67.1)	55.3±59.6 (34.4)	[1]p = 0.27; *d* = 0.72[M]
Post	74.6±72.5 (41.9)	133.6±240.5 (133.2)	[2]p = 0.28; *d* = 0.34[S]
	[3]p = 0.43; *d* = 0.47[M]	[4]p = 0.14; *d* = 0.46[M]	
Stride length			
Pre	16.9±10.5 (6.35)	15.4±13.2 (7.3)	[1]p = 0.67; *d* = 0.13[N]
Post	9.8±11.4 (6.6)	14.5±8.3 (4.6)	[2]p = 0.26; *d* = 0.49[M]
	[3]p = 0.02*; *d* = 0.67[M]	[4]p = 0.74; *d* = 0.08[N]	
Stride length CoV			
Pre	65.9±77.3 (46.7)	24.8±47.4 (27.4)	[1]p = 0.10; *d* = 0.67[M]
Post	28.1±59.4 (34.27)	13.5±65.9 (36.5)	[2]p = 0.54; *d* = 0.24[S]
	[3]p = 0.13; *d* = 0.57[M]	[4]p = 0.63; *d* = 0.20[S]	
Cadence			
Pre	12.0±12.6 (7.6)	10.4±4.9 (2.8)	[1]p = 0.79; *d* = 0.18[S]
Post	12.6±7.2 (4.2)	14.2±10.7 (5.9)	[2]p = 0.82; *d* = 0.18[S]
	[3]p = 0.36; *d* = 0.06[N]	[4]p = 0.71; *d* = 0.47[M]	
Cadence CoV			
Pre	110.4±100.9 (61.0)	59.1±63.0 (36.4)	[1]p = 0.31; *d* = 0.64[M]
Post	62.5±55.2 (31.9)	113.5±190.8 (105.7)	[2]p = 0.27; *d* = 0.45[M]
	[3]p = 0.46; *d* = 0.61[M]	[4]p = 0.14; *d* = 0.40[M]	
% Double support			
Pre	20.7±16.6 (10.1)	13.8±19.6 (11.3)	[1]p = 0.25; *d* = 0.39[S]
Post	16.8±13.7 (7.9)	22.0±18.4 (10.2)	[2]p = 0.42; *d* = 0.33[S]
	[3]p = 0.33; *d* = 0.27[S]	[4]p = 0.05*; *d* = 0.45[M]	

Table 5.2 cont. Percentage dual task interference of selected gait variables where higher values indicate deterioration and lower values indicate improvement. Values are mean±SD (95% Confidence Interval)

% Double support CoV			
Pre	**32.0±48.5 (29.3)**	**37.4±75.3 (43.5)**	**[1]p = 0.82; *d* = 0.09[N]**
Post	**15.4±44.7 (25.8)**	**3.4±42.9 (23.7)**	**[2]p = 0.36; *d* = 0.28[S]**
	[3]p = 0.42; *d* =0.37[S]	**[4]p = 0.05*; *d* =0.57[M]**	
Step duration GA			
Pre	22.7±131.5 (79.5)	126.1±389.9 (225.1)	[1]p = 0.85; *d* = 0.36[S]
Post	64.6±147.1 (84.9)	816.0±2654.8 (1470.2)	[2]p = 0.16; *d* = 0.19[S]
	[3]p = 0.94; *d* = 0.31[S]	[4]p = 0.19; *d* = 0.38[S]	
Swing time GA			
Pre	127.3±206.0 (124.5)	54.7±132.1 (76.3)	[1]p = 0.44; *d* = 0.44[M]
Post	69.4±104.7 (60.5)	253.0±457.7 (253.5)	[2]p = 0.08^; *d* = 0.56[M]
	[3]p = 0.50; *d* = 0.37[S]	[4]p = 0.02*; *d* = 0.61[M]	

*p≤0.05; ^p<0.09
[1]Group difference: Baseline; [2]Group difference: Post-test; [3]FWG: Over time; [4]BWG: Over time
[N]Negligible ES; [S]Small ES; [M]Medium ES
Abbreviations: CoV = Coefficient of Variance; GA = gait asymmetry; ES = Effect size

The weekly average Rating of Perceived Exertion (RPE) of the FWG were higher than that of the BWG (p<0.01), showing that there was a between-group difference in weekly load (*Figure 5.2*).

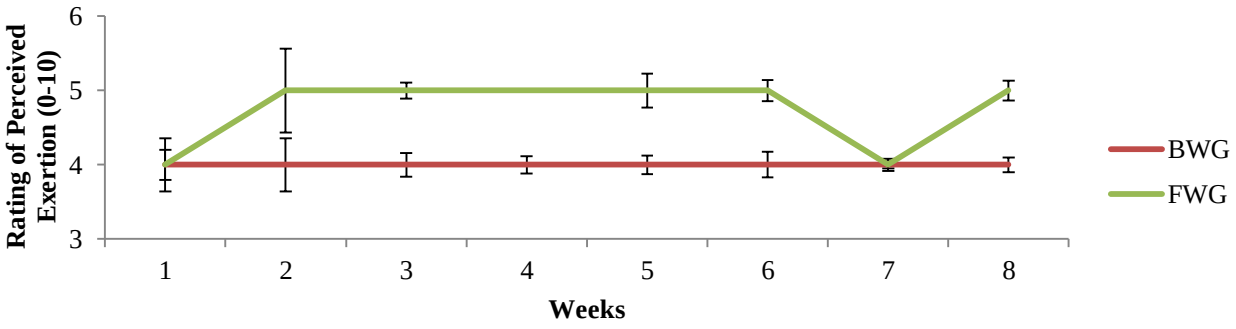


Figure 5.2 Rating of Perceived Exertion of the FWG and BWG over the eight weeks

5.5 Discussion

The current study aimed to compare eight weeks of BW and FW gait retraining on DT interference during walking in individuals with mild to moderate PD. The main findings of this study were improved (decreased) DT interference for stride length (SL) of the FWG and for percentage double support (%DS) CoV of the BWG as well as deteriorated (increased) DT interference for %DS and swing time gait asymmetry (GA) in the BWG. Furthermore, the FWG

improved scores for experiences of daily living (UPDRS II). To the researchers' knowledge, this is the first study to compare DT interference after over ground FW and BW gait retraining in PD.

Considering the difficulty of the two training methods, it becomes clear that the FWG consistently had higher RPE. Compared to BW, FW is a well-known task. Keeping in mind that PD individuals have balance impairments, one can deduct that the FWG were able to exercise at higher intensities while the BWG could not have increased the intensity as much, as their training task was novel and much more complex. Taken together, even though BW was more difficult, it did not yield higher ratings of perceived exertion. Firstly, this indicates that the BWG created safe environments for themselves that did not require exertion. Secondly, the lower levels of exertion might be the reason for limited neural improvements, as it is well known that neural changes require sufficient intensities.

By focussing attention on walking, PD individuals can improve their gait pattern; however, under DT conditions, gait deteriorates [42]. This was seen for all variables reported in this article. A discussion of significant findings follows.

5.5.1 Decreased interference over time for SL in the FWG

The inability to generate a normal SL is the fundamental gait problem in PD as it gives an indication of the characteristic PD shuffling gait pattern, which can be a large contributor to falls [43]. Considering that he maintenance of SL is controlled by the basal ganglia [44], FW gait retraining is effective for improving automatic control of gait under DT conditions. This is a major positive finding considering fall risk in PD and the increased neural efficiency will ultimately carry over to daily functionality [45]. This was shown by improved UPDRS II scores in the FWG.

MDS-UPDRS Part II relates to PD-specific experiences of daily living (ADL). Only the FWG improved their ADL scores over time. This demonstrates the positive impact of an over ground forwards gait retraining program on PD-related QoL. A study on slightly younger PD individuals with the same disease duration reported a score of 16.0±10.0 on the MDS-UPDRS II [46]. In response to the intervention, the FWG improved their ADL scores to below this score to a value that is comparable to that of the BWG. Considering these results, it seems that the FWG's training activities more closely relate to ADL, compared to the BWG, making the transfer of the exercises to daily life easier.

Gait automaticity improvements have been found previously in a study on cued gait tasks under ST and DT conditions. In response to the training program, improvements in gait speed and step

length under both conditions without the use of cues were reported. These improvements remained for six weeks after the intervention [47]. Other DT training studies reported improved ST and DT gait speed and SL when walking was prioritized during training [48,49] as well as when attention was equally divided between tasks during training [49]; however the concurrent task during training was similar than that used during testing. This is in contrast to the current study despite similar outcomes. In line with the current study, Canning et al. (2008) utilized different DT during training and testing with equally divided and reported improved gait speed and cadence.

5.5.2 Increased interference over time for %DS in the BWG

Time spent in DS phase of the GC generally reflects postural stability. Compared to healthy, matched elderly individuals, PD individuals spend more time in DS under DT conditions [26]. Despite the negative association of %DS with FOG and anti-Parkinson medication usage [51,52], neither of these two variables had an influence in the current study. Results for the FOG-Q remained unchanged over the study period and time since medication intake did not differ between groups at any time point.

Longer DS phases reflects an inability to control the body's centre of mass while performing a long swing time [52]. Transition from DS phase to single-limb stance is challenging for PD individuals as they need to maintain postural stability while their weight is shifted from a stable position (DS) to a relatively unstable position (smaller base of support with single-limb stance) [53]. Considering the novelty of BW, the BWG required constant conscious control to transfer the body from DS to single-limb support. It is possible that the BWG became accustomed to conscious control of stability; however at post-testing, the division of attention between FW and the DT became distorted and reflected that postural stability were not subconsciously or automatically maintained. Furthermore, a recent study reported that increased DS time while walking reflects perceived mobility disability [54]. This finding is however in contrast to results of the current study, as the BWG objectively increased their DS time whilst subjectively improving their PDQ-39 mobility domain. As Curtze et al. (2016) reported on ST walking, findings under DT walking in the current study highlights the difficulty PD individuals have with performing a motor and cognitive task simultaneously.

5.5.3 Decreased interference over time for % DS variability in the BWG

Increased stride-to-stride variability is a marker of rhythmicity and reduced automaticity during walking, indicating unsteadiness and risk of falling [23]. In PD, automaticity is impaired and the

need to recruit additional, compensatory resources for restricted attention rises [55]. Under DT conditions, deficits in automaticity and stability of the gait pattern is highlighted [8], as was seen in the current study.

Variability in double support is reflective of dynamic postural control mechanisms for gait [23,51]. Under DT conditions, DS variability is influenced by age, attention and UPDRS III scores [51,55]. As DS variability is independent of dopamine, it suggests the role of the PPN (pedunculopontine nucleus) in the control of balance [51]. Moreover, it suggests that BW had an impact on the PPN.

Generally, the ability to DT is determined by executive functioning and the ability to divide attention. In PD, gait regulation, demonstrated by rhythmicity and variability which normally is automatic processes, are highly attention-demanding [55]. Considering that the BWG had superior results to the FWG, one can deduct that the high levels of attention needed to perform BW [56] might have allowed the BWG to meet the challenges of attention-demanding tasks more effectively, such as what was used during testing. In other words, training in a highly attention-demanding task, i.e. BW, can improve internal cueing mechanisms in PD, which transforms the regulation of gait rhythmicity into a less attention-demanding task [55].

Gait variability is generally related to increased risk of falling, but not to fear of falling [57]. As the BWG improved their DS variability, they lowered their risk of falling by improving their balance control abilities [57]; however, the increased %DS reflects their fear of falling under DT conditions. Unfortunately, this study did not include specific measures for risk and fear of falling. As the BWG consistently had lower weekly averages for RPE scores, it might reflect their fear of falling and show that they did not exert themselves beyond what they feel safe with. Taken together, it seems that under DT conditions, the BWG had decreased stability in compensation to fear of falling, but improved control over the walking pattern. This finding is in line with impaired stability measures under ST conditions, as explained with SL variability in the BWG.

5.5.4 Increased interference over time for Swing time GA in the BWG

In theory, an automated gait parameter would not require cognitive function and therefore the addition of a secondary task will not influence the outcome of this parameter. Alternatively, if this parameter is dependent on cognitive abilities, available cognitive resources are divided during DT. This is supported by the capacity sharing theory, where performance in both or one of the two tasks deteriorates [26,55]. Gait asymmetry is an index of coordination between left

and right limbs and, due to its complexity, requires additional cognitive input. Moreover, when a secondary task is added, regulation of GA becomes even more sensitive to cognitive loading [58], as gait is forced to become more automatic to allow more attention for the secondary task [51]. Taken together, GA is not associated with executive function or attention, but it is rather sensitive to the way in which participants differently allocates attention to different tasks [58]. This suggests that while participants performed the test, attention was increased and decreased to focus more on walking and the DT alternatively, consequently creating asymmetry.

Findings from the current study are in line with previous research that found increased GA during DT in PD individuals compared to elderly fallers [58]. This was also found in post-stroke individuals, where impaired gait automaticity influences left-right coordination, which is sensitive to DT [59].

As PD becomes more severe, GA worsens, is more severe among PD freezers and is sensitive to anti-Parkinson medication deprivation [58]. The relationship between motor severity and variability, especially under DT conditions, highlights the difficulty PD individuals have with cognitive control to compensate for basal ganglia dysfunction [51]. In healthy elderly individuals, gait asymmetry is also related to limb dominance, disease, leg length discrepancies and strength imbalances [60]. Of these factors, disease, lower limb dominance and strength imbalances could have had an influence on GA outcomes. The current study however did not include participants' dominant side or objective muscle strength measures. Regarding the influence of disease on GA, PD individuals generally presents with increased GA, particularly under DT conditions, compared to healthy, elderly fallers [55]. Despite improvements in motor symptom severity and bradykinesia scores in the BWG, it did not relate to improved GA under DT conditions. Even though it was not investigated in the current study, it is possible that the BW gait retraining program induced asymmetrical improvements in PD-related symptoms, as expressed by worsened GA while walking. The degree of GA in early PD is however not associated with severity of asymmetry in motor symptoms, such as tremor or rigidity [58].

Changes in GA over time can be attributed to the specificity of the training tasks. While the FWG trained to restore automatic skills, the BWG learned a new skill. Although attentional skills could have been enhanced with BW, the ability to share attention between a cognitive and motor task remained difficult. Moreover, it is possible that the BWG allocated more attention to the cognitive task than the motor task during the post-test, reflecting their underlying coordinative difficulties. It was previously reported that PD individuals use a strategy where gait and posture receives attention secondary to the DT [45]. These findings suggest that GA occurs

in compensation to an alternative underlying impairment that was not addressed in the BW, but was maintained with FW.

Considering that BW presumably made use of cortical resources rather than the basal ganglia, it is possible that lower level spinal centres might regulate left-right coordination [58]. Cortical loops are however limited, require high-levels of cognitive function and influences executive function and attention in PD. The BWG became accustomed to making use of these loops during training, but under testing conditions, these compensatory neural loops became even more limited, resulting in increased DTC of swing time GA. In other words, the use of a secondary task removes the attention from the most automatic movement, in this case walking, and directs attention to the required task, in this case the cognitive task. Therefore, the automatic task uses the basal ganglia – supplementary motor area (SMA) loop and results in deteriorated gait parameters. While the BWG made use of cortical loops during training, the FWG made use of basal ganglia-SMA loops to thereby maintain their gait parameters under DT conditions.

5.5.5 Limitations and future studies

Due to the novelty of the current investigation, there is plenty suggestions for future studies.

Firstly, a motor-cognitive test, such as a walking Stroop test should be used to more accurately assess executive function in PD.

Secondly, although most gait parameters can be accurately measured over short distances and with a small amount of strides, there are descrepancies in literature regarding which protocol is best to measure the variability of these measures [61,62]. Unfortunately, the i10m-walkway used in the current study possibly might have had an impact on findings from the current study. Thirdly, participants were not instructed on how to prioritize their attention when a DT was added during training or testing. It is been reported that specific instructions regarding prioritization may reduce the DT decrement for the prioritized task [45]; however, results are inconsistent. Lastly, considering that walking while performing a secondary task can be hazardous for individuals with severe PD, only mild to moderate PD individuals were included in the current study. Results of this study should thus not be generalized to other PD severity stages.

5.5.6 Conclusion

Considering these findings, interventions designed to decrease DT cost during gait should focus on both motor and cognitive deficits. It is suggested that in individuals with neurological

conditions, the ability to re-learn motor tasks remains intact and therefore the ability to train DT abilities is also possible [45]. In PD individuals, the ability to compensate for impaired walking parameters is limited due to decreased cognitive reserve. It seems that under DT conditions, the BWG had decreased stability in compensation to fear of falling, but improved control over the walking pattern. In contrast to the BWG, the FWG improved automaticity of gait control under DT conditions.

5.5.7 Acknowledgements

The researchers are immensely grateful for the participants for their time and effort to complete the intervention, for Miss EM Atterbury for assisting with the exercise sessions as well as Prof M Kidd for assisting with the statistical analyses. The authors would also like to acknowledge the Department of Sport Science (Stellenbosch University) and National Research Foundation (NRF, South Africa) for their financial support for this publication.

5.6 References

[1] A. Nagal, R.K. Singla, Parkinson's Disease : Diagnosis , Therapeutics & Management Parkinson's Disease : Diagnosis , Therapeutics & Management, WebmedCentral Pharm. Sci. 3 (2016) WMC003670. http://www.webmedcentral.com/article_view/3670 Subject.

[2] V.E. Kelly, A.J. Eusterbrock, A. Shumway-Cook, A review of dual-task walking deficits in people with Parkinson's disease: Motor and cognitive contributions, mechanisms, and clinical implications, Parkinsons. Dis. 2012 (2012). doi:10.1155/2012/918719.

[3] C. Strouwen, E.A.L.M. Molenaar, L. Munks, S.H.J. Keus, B.R. Bloem, L. Rochester, A. Nieuwboer, Dual tasking in Parkinson's disease: should we train hazardous behavior?, Expert Rev. Neurother. 15 (2015) 1031–1039. doi:10.1586/14737175.2015.1077116.

[4] J.M. Hausdorff, G. Yogev, S. Springer, E.S. Simon, N. Giladi, Walking is more like catching than tapping: Gait in the elderly as a complex cognitive task, Exp. Brain Res. 164 (2005) 541–548. doi:10.1007/s00221-005-2280-3.

[5] B.R. Bloem, J.M. Hausdorff, J.E. Visser, N. Giladi, Falls and freezing of Gait in Parkinson's disease: A review of two interconnected, episodic phenomena, Mov. Disord. 19 (2004) 871–884. doi:10.1002/mds.20115.

[6] S. Koch, R.W. Holland, M. Hengstler, A. Van Knippenberg, Body Locomotion as Regulatory Process Stepping Backward Enhances Cognitive Control, 20 (2009) 549–551.

[7] G. Alves, E.B. Forsaa, K.F. Pedersen, M. Dreetz Gjerstad, J.P. Larsen, Epidemiology of Parkinson's disease, J. Neurol. 255 (2008) 18–32. doi:10.1007/s00415-008-5004-3.

[8] S.G. Brauer, M.H. Woollacott, R. Lamont, S. Clewett, J. O'Sullivan, P. Silburn, G.D. Mellick, M.E. Morris, Single and dual task gait training in people with Parkinson's disease: a protocol for a randomised controlled trial., BMC Neurol. 11 (2011) 90. doi:10.1186/1471-2377-11-90.

[9] M.E. Morris, R. Iansek, T. a Matyas, J.J. Summers, Stride length regulation in Parkinson â€^{TM} s disease Normalization strategies and underlying mechanisms, Brain. 119 (1996) 551–568. doi:10.1093/brain/119.2.551.

[10] G.M. Petzinger, B.E. Fisher, S. McEwen, J.A. Beeler, J.P. Walsh, M.W. Jakowec, Exercise-enhanced neuroplasticity targeting motor and cognitive circuitry in Parkinson's disease, Lancet Neurol. 12 (2013) 716–726. doi:10.1016/S1474-4422(13)70123-6.

[11] N. Hedayatpour, D. Falla, Physiological and Neural Adaptations to Eccentric Exercise: Mechanisms and Considerations for Training, Biomed Res. Int. 2015 (2015). doi:10.1155/2015/193741.

[12] M.M. Hoehn, M.D. Yahr, Parkinsonism : onset , progression , and mortality, 17 (1967). doi:10.1212/WNL.17.5.427.

[13] C.G. Goetz, S. Fahn, P. Martinez-Martin, W. Poewe, C. Sampaio, G.T. Stebbins, M.B. Stern, B.C. Tilley, R. Dodel, B. Dubois, R. Holloway, J. Jankovic, J. Kulisevsky, A.E. Lang, A. Lees, S. Leurgans, P.A. LeWitt, D. Nyenhuis, C.W. Olanow, O. Rascol, A. Schrag, J.A. Teresi, J.J. Van Hilten, N. LaPelle, Movement disorder society-sponsored revision of the unified Parkinson's disease rating scale (MDS-UPDRS): Process, format, and clinimetric testing plan, Mov. Disord. 22 (2007) 41–47. doi:10.1002/mds.21198.

[14] G.T. Stebbins, C.G. Goetz, D.J. Burn, J. Jankovic, T.K. Khoo, B.C. Tilley, How to identify tremor dominant and postural instability/gait difficulty groups with the movement disorder society unified Parkinson's disease rating scale: Comparison with the unified Parkinson's disease rating scale, Mov. Disord. 28 (2013) 668–670. doi:10.1002/mds.25383.

[15] T. Steffen, M. Seney, Test-retest reliability and minimal detectable change on balance and ambulation tests, the 36-item short-form health survey, and the unified Parkinson disease rating scale in people with parkinsonism., Phys. Ther. 88 (2008) 733–746. doi:10.2522/ptj.20070214.

[16] R.P. Duncan, A.L. Leddy, G.M. Earhart, Five Times Sit to Stand Test Performance in Parkinson Disease, Arch. Phys. Med. Rehabil. 92 (2011) 1431–1436. doi:10.1016/j.apmr.2011.04.008.Five.

[17] M. Mancini, F.B. Horak, Potential of APDM Mobility Lab for the monitoring of the progression of Parkinson's disease, Expert Rev. Med. Devices. 4440 (2016) 17434440.2016.1153421. doi:10.1586/17434440.2016.1153421.

[18] M.A. Simoes, Feasibility of Wearable Sensors to Determine Gait Parameters, Dep. Mech. Eng. Master of (2011) 108. doi:10.1007/s13398-014-0173-7.2.

[19] L.I.I.K. Lim, E.E.H. Van Wegen, C.J.T. De Goede, D. Jones, L. Rochester, V. Hetherington, A. Nieuwboer, A.M. Willems, G. Kwakkel, Measuring gait and gait-related activities in Parkinson's patients own home environment: A reliability, responsiveness and feasibility study, Park. Relat. Disord. 11 (2005) 19–24. doi:10.1016/j.parkreldis.2004.06.003.

[20] M. Plotnik, N. Giladi, Y. Balash, C. Peretz, J.M. Hausdorff, Is freezing of gait in Parkinson's disease related to asymmetric motor function?, Ann. Neurol. 57 (2005) 656–663. doi:10.1002/ana.20452.

[21] R.L. Fuller, E.P. Van Winkle, K.E. Anderson, A.L. Gruber-Baldini, T. Hill, C. Zampieri, W.J. Weiner, L.M. Shulman, Dual task performance in Parkinson's disease: A sensitive predictor of impairment and disability, Park. Relat. Disord. 19 (2013) 325–328. doi:10.1016/j.parkreldis.2012.11.011.

[22] E.M. Atterbury, Home-based balance training for dynamic balance in independent- living individuals with Parkinson's disease, Dr. Diss. Stellenbosch Univ. (2015).

[23] S. Springer, N. Giladi, C. Peretz, G. Yogev, E.S. Simon, J.M. Hausdorff, Dual-tasking effects on gait variability: The role of aging, falls, and executive function, Mov. Disord. 21 (2006) 950–957. doi:10.1002/mds.20848.

[24] M. Plotnik, N. Giladi, Y. Dagan, J.M. Hausdorff, Postural instability and fall risk in Parkinson's disease: Impaired dual tasking, pacing, and bilateral coordination of gait during the "oN" medication state, Exp. Brain Res. 210 (2011) 529–538. doi:10.1007/s00221-011-2551-0.

[25] G. Yogev-Seligmann, N. Giladi, M. Brozgol, J.M. Hausdorff, A training program to improve gait while dual tasking in patients with Parkinson's disease: A pilot study, Arch. Phys. Med. Rehabil. 93 (2012) 176–181. doi:10.1016/j.apmr.2011.06.005.

[26] S. O'Shea, M.E. Morris, R. Iansek, Research Report in People With Parkinson Disease : Effects of Motor Versus Cognitive, J. Am. Phys. Ther. Assoc. 82 (2002) 888–897.

[27] P. Plummer, G. Eskes, Measuring treatment effects on dual-task performance: a framework for research and clinical practice., Front. Hum. Neurosci. 9 (2015) 225. doi:10.3389/fnhum.2015.00225.

[28] P. Martinez-Martin, C. Rodriguez-Blazquez, M.M. Kurtis, K.R. Chaudhuri, The impact of non-motor symptoms on health-related quality of life of patients with Parkinson's disease, Mov. Disord. 26 (2011) 399–406. doi:10.1002/mds.23462.

[29] J.C. Dalrymple-Alford, M.R. MacAskill, C.T. Nakas, L. Livingston, C. Graham, G.P. Crucian, T.R. Melzer, J. Kirwan, R. Keenan, S. Wells, R.J. Porter, R. Watts, T.J. Anderson, The MoCA: Well-suited screen for cognitive impairment in Parkinson disease, Neurology. 75 (2010) 1717–1725. doi:10.1212/WNL.0b013e3181fc29c9.

[30] S. Hoops, S. Nazem, A.D. Siderowf, J.E. Duda, S.X. Xie, M.B. Stern, D. Weintraub, Validity of the MoCA and MMSE in the detection of MCI and dementia in Parkinson disease, Neurology. 73 (2009) 1738–1745. doi:10.1212/WNL.0b013e3181c34b47.

[31] K. Kroenke, R.L. Spitzer, J.B.W. Williams, The PHQ-9: Validity of a brief depression severity measure, J. Gen. Intern. Med. 16 (2001) 606–613. doi:10.1046/j.1525-1497.2001.016009606.x.

[32] M.H.N. Chagas, V. Tumas, G.R. Rodrigues, J.P. Machado-De-Sousa, A.S. Filho, J.E.C. Hallak, J.A.S. Crippa, Validation and internal consistency of patient health questionnaire-9 for major depression in parkinson's disease, Age Ageing. 42 (2013) 645–649. doi:10.1093/ageing/aft065.

[33] G. Abbruzzese, R. Marchese, L. Avanzino, E. Pelosin, Rehabilitation for Parkinson's disease: Current outlook and future challenges, Park. Relat. Disord. 22 (2016) S60–S64. doi:10.1016/j.parkreldis.2015.09.005.

[34] G. Brichetto, E. Pelosin, R. Marchese, G. Abbruzzese, Evaluation of physical therapy in parkinsonian patients with freezing of gait : a pilot study, Clin. Rehabil. 20 (2006) 31–35. doi:10.1191/0269215506cr913oa.

[35] A. Nieuwboer, G. Kwakkel, L. Rochester, D. Jones, E. van Wegen, a M. Willems, F. Chavret, V. Hetherington, K. Baker, I. Lim, Cueing training in the home improves gait-related mobility in Parkinson's disease: the RESCUE trial., J. Neurol. Neurosurg. Psychiatry. 78 (2007) 134–140. doi:10.1136/jnnp.200X.097923.

[36] C. Peters, M. Currin, S. Tyson, A. Rogers, S. Healy, S. McPhail, S.G. Brauer, K. Heathcote, T. Comans, A randomized controlled trial of an enhanced interdisciplinary community based group program for people with Parkinson's disease: study rationale and protocol., Neurol. Int. 4 (2012) e3. doi:10.4081/ni.2012.e3.

[37] D.S. Peterson, M. Plotnik, J.M. Hausdorff, G.M. Earhart, Evidence for a relationship between bilateral coordination during complex gait tasks and freezing of gait in Parkinson's disease, Park. Relat. Disord. 18 (2012) 1022–1026. doi:10.1016/j.parkreldis.2012.05.019.

[38] S. Keus, M. Munneke, M. Graziano, J. Paltamaa, E. Pelosin, J. Domingos, B. Ramaswamy, J. Prins, C. Struiksma, L. Rochester, A. Nieuwboer, B. Bloem, European Physiotherapy Guideline for Parkinson ' s Disease Developed with twenty European professional associations, KNGF/ParkinsonNet, the Netherlands. 1 (2014) 32.

[39] X. Shen, M.K.Y. Mak, Balance and Gait Training With Augmented Feedback Improves Balance Confidence in People With Parkinson's Disease: A Randomized Controlled Trial., Neurorehabil. Neural Repair. 28 (2014) 524–535. doi:10.1177/1545968313517752.

[40] T. Gregory, K. Welman, Somatosensory training for postural control in independent-living individuals with Parkinson's disease, Dr. Diss. Stellenbosch Univ. (2015).

[41] W. Thalheimer, S. Cook, How to calculate effect sizes from published research: A simplified methodology, Work. Res. (2002) 1–9. doi:10.1113/jphysiol.2004.078915.

[42] J.P. Azulay, S. Mesure, O. Blin, Influence of visual cues on gait in Parkinson's disease: Contribution to attention or sensory dependence?, J. Neurol. Sci. 248 (2006) 192–195. doi:10.1016/j.jns.2006.05.008.

[43] M.S. Bryant, D.H. Rintala, J.G. Hou, A.L. Charness, A.L. Fernandez, R.L. Collins, J. Baker, E.C. Lai, E.J. Protas, Gait variability in Parkinson's disease: influence of walking speed and dopaminergic treatment, Neurol. Res. 33 (2011) 959–964. doi:10.1179/1743132811Y.0000000044.

[44] M. Danoudis, R. Iansek, Gait in Huntington¿s disease and the stride length-cadence relationship., BMC Neurol. 14 (2014) 161. doi:10.1186/s12883-014-0161-8.

[45] G. Yogev-Seligmann, J.M. Hausdorff, N. Giladi, The role of executive function and attention in gait, Mov. Disord. 23 (2008) 329–342. doi:10.1002/mds.21720.

[46] C.G. Goetz, B.C. Tilley, S.R. Shaftman, G.T. Stebbins, S. Fahn, P. Martinez-Martin, W. Poewe, C. Sampaio, M.B. Stern, R. Dodel, B. Dubois, R. Holloway, J. Jankovic, J. Kulisevsky, A.E. Lang, A. Lees, S. Leurgans, P.A. LeWitt, D. Nyenhuis, C.W. Olanow, O. Rascol, A. Schrag, J.A. Teresi, J.J. van Hilten, N. LaPelle, P. Agarwal, S. Athar, Y. Bordelan, H.M. Bronte-Stewart, R. Camicioli, K. Chou, W. Cole, A. Dalvi, H. Delgado, A. Diamond, J.P. Dick, J. Duda, R.J. Elble, C. Evans, V.G. Evidente, H.H. Fernandez, S. Fox, J.H. Friedman, R.D. Fross, D. Gallagher, C.G. Goetz, D. Hall, N. Hermanowicz, V. Hinson, S. Horn, H. Hurtig, U.J. Kang, G. Kleiner-Fisman, O. Klepitskaya, K. Kompoliti, E.C. Lai, M.L. Leehey, I. Leroi, K.E. Lyons, T. McClain, S.W. Metzer, J. Miyasaki, J.C. Morgan, M. Nance, J. Nemeth, R. Pahwa, S.A. Parashos, J.S.J.S. Schneider, A. Schrag, K. Sethi, L.M. Shulman, A. Siderowf, M. Silverdale, T. Simuni, M. Stacy, M.B. Stern, R.M. Stewart, K. Sullivan, D.M. Swope, P.M. Wadia, R.W. Walker, R. Walker, W.J. Weiner, J. Wiener, J. Wilkinson, J.M. Wojcieszek, S. Wolfrath, F. Wooten, A. Wu, T.A. Zesiewicz, R.M. Zweig, Movement Disorder Society-Sponsored Revision of the Unified Parkinson's Disease Rating Scale (MDS-UPDRS): Scale presentation and clinimetric testing results, Mov. Disord. 23 (2008) 2129–2170. doi:10.1002/mds.22340.

[47] L. Rochester, V. Hetherington, D. Jones, A. Nieuwboer, A.M. Willems, G. Kwakkel, E. Van Wegen, The effect of external rhythmic cues (auditory and visual) on walking during a functional task in homes of people with Parkinson's disease, Arch. Phys. Med. Rehabil. 86 (2005) 999–1006. doi:10.1016/j.apmr.2004.10.040.

[48] C.G. Canning, The effect of directing attention during walking under dual-task conditions in Parkinson's disease, Park. Relat. Disord. 11 (2005) 95–99. doi:10.1016/j.parkreldis.2004.09.006.

[49] P. Fok, M. Farrell, J. McMeeken, Y.-L. Kuo, The effects of verbal instructions on gait in people with Parkinson's disease: a systematic review of randomized and non-randomized trials., Clin. Rehabil. 25 (2011) 396–407. doi:10.1177/0269215510387648.

[50] C.G. Canning, L. Ada, E. Woodhouse, Multiple-task walking training in people with mild to moderate Parkinson ' s disease : a pilot study, Clin. Rehabil. 22 (2008) 226–233.

[51] S. Lord, K. Baker, A. Nieuwboer, D. Burn, L. Rochester, Gait variability in Parkinson's disease: An indicator of non-dopaminergic contributors to gait dysfunction?, J. Neurol. 258 (2011) 566–572. doi:10.1007/s00415-010-5789-8.

[52] K. Smulders, M.L. Dale, P. Carlson-kuhta, J.G. Nutt, F.B. Horak, Parkinsonism and Related Disorders Pharmacological treatment in Parkinson â€™ s disease : Effects on gait, Park. Relat. Disord. (2016). doi:10.1016/j.parkreldis.2016.07.006.

[53] M. Tramontano, S. Bonnì, A. Martino Cinnera, F. Marchetti, C. Caltagirone, G. Koch, A. Peppe, Blindfolded Balance Training in Patients with Parkinson's Disease: A Sensory-Motor Strategy to Improve the Gait, Parkinsons. Dis. 2016 (2016). doi:10.1155/2016/7536862.

[54] C. Curtze, J.G. Nutt, P. Carlson-Kuhta, M. Mancini, F.B. Horak, Objective Gait and Balance Impairments Relate to Balance Confidence and Perceived Mobility in People With Parkinson's Disease., Phys. Ther. (2016) ptj.20150662-. doi:10.2522/ptj.20150662.

[55] G. Yogev, N. Giladi, C. Peretz, S. Springer, E.S. Simon, J.M. Hausdorff, Dual tasking, gait rhythmicity, and Parkinson's disease: Which aspects of gait are attention demanding?, Eur. J. Neurosci. 22 (2005) 1248–1256. doi:10.1111/j.1460-9568.2005.04298.x.

[56] G.N. Lewis, W.D. Byblow, S.E. Walt, Stride length regulation in Parkinson's disease: the use of extrinsic, visual cues., Brain. 123 (Pt 1 (2000) 2077–2090. doi:10.1093/brain/123.10.2077.

[57] J.M. Hausdorff, Gait variability : methods , modeling and meaning Example of Increased Stride Time Variability in Elderly Fallers Quantification of Stride-to-Stride Fluctuations, 9 (2005) 1–9. doi:10.1186/1743-0003-2-19.

[58] G. Yogev, M. Plotnik, C. Peretz, N. Giladi, J.M. Hausdorff, Gait asymmetry in patients with Parkinson's disease and elderly fallers: When does the bilateral coordination of gait require attention?, Exp. Brain Res. 177 (2007) 336–346. doi:10.1007/s00221-006-0676-3.

[59] Y.-R. Yang, R.-Y. Wang, Y.-C. Chen, M.-J. Kao, Dual-task exercise improves walking ability in chronic stroke: a randomized controlled trial., Arch. Phys. Med. Rehabil. 88 (2007) 1236–1240. doi:10.1016/j.apmr.2007.06.762.

[60] D.P. LaRoche, S.B. Cook, K. Mackala, Strength Asymmetry Increases Gait Asymmetry and Variability in Older Women, 44 (2012) 2172–2181. doi:10.1249/MSS.0b013e31825e1d31.

[61] B. Galna, S. Lord, L. Rochester, Is gait variability reliable in older adults and Parkinson's disease? Towards an optimal testing protocol, Gait Posture. 37 (2013) 580–585. doi:10.1016/j.gaitpost.2012.09.025.

[62] N. König, N.B. Singh, C.R. Baumann, W.R. Taylor, Can Gait Signatures Provide Quantitative Measures for Aiding Clinical Decision-Making? A Systematic Meta-Analysis of Gait Variability Behavior in Patients with Parkinson's Disease., Front. Hum. Neurosci. 10 (2016) 319. doi:10.3389/fnhum.2016.00319.

CHAPTER 6

General Discussion and Conclusion

6.1 Introduction

The purpose of this chapter is to give a general overview of the main research findings with regard to the research questions listed in Chapter 2. Furthermore, general conclusions based on the findings, together with limitations and recommendations for future studies are presented. Backward walking (BW) and forward walking (FW) require the same motor program It is thought that BW may offer some more benefits than forward walking (FW), i.e. induce more muscle activity (Woo et al. 2009; Blazkiewicz 2013), greater level of energy and oxygen consumption (Terblanche et al. 2005; Woo et al. 2009), greater metabolic and cardiorespiratory response (Cha et al. 2016), improved postural stability (El-Basatiny & Abdel-Aziem 2015) as well as improved walking speed and mobility (Taipei et al. 2005; DePaul et al. 2011; Kim et al. 2013; Michaelsen et al. 2014).

Consequently, the primary aim of this study was to compare an eight-week BW to a FW gait retraining program on the mobility of individuals with mild to moderate Parkinson's disease (PD). A secondary aim was to assess the effect of these gait retraining programs on functional capacity, perceived balance confidence and quality of life (QoL). To address these aims, spatiotemporal gait parameters, postural transitions and turning variables were assessed under single (ST) and dual (DT) task conditions. Also, participants performed a six-minute-walk-test (6MWT) and information on disease severity, disease-related QoL, balance confidence and freezing statuses were collected. Using the Grubbs and Dixon test, outliers were found for PHQ-9 as well as for variability in cadence, GC time and %DS; however, none of these outcomes changed when the analyses were done without the outliers.

The following sections elaborate on the main findings after the eight-week FW and BW gait retraining intervention as they relate to the respective objectives.

6.2 Participants

Participants in this study had similar baseline scores for all demographic variables as described in the following sub-headings.

6.2.1 Gender

Of the 29 participants (aged 71.0±8.8 years) who completed the study, 19 were men and 10 were women; however, men and women were similarly divided between groups. It is well reported

that men above the age of 60 years, have a higher PD incidence rate than women above 60 years (Wirdefeldt et al. 2011); hence, the higher number of men (65.5% men) in the current study is not surprising. As men and women respond differently to training, it might be that the higher proportion men could have influenced the outcome of the results. Therefore, the generalizability of the results should be carefully considered.

6.2.2 Fall risk

The effect of aging and disease duration on PD-related motor symptoms has been reported previously (Alves et al. 2008). Postural instability specifically can be experienced by up to 65% of PD individuals with disease duration of five years, which highly affects mobility and contributes to an increased fall risk (Bloem et al. 2004; Nagal & Singla 2016). Up to 68% of PD individuals fall at least once a year and 50% of them fall repeatedly (Allen et al. 2010). As participants in the current study have a disease duration of 6.0±5.0 years (FWG: 7.0±6.0; BWG: 5.0±3.0), their risk of falling is evident. Moreover, most older adults who are hospitalized as a result of falling, are over the age of 65 years (Hill et al. 2015). Participants in the FWG and BWG were 70.0±11.0 years and 72.0±6.0 years of age, respectively, placing them at an age-related fall risk. This highlights the importance of strategies to improve the fall risk of PD individuals, who experience age- as well as disease-related factors relating to falling. Previous reports state that PD fallers generally have more stride time variability and a slower walking speed with shorter steps than PD non-fallers (Cole et al. 2010). In the current study, all participants improved their gait speed, suggesting the positive impact of the FW and BW interventions on possible fall risk. Additionally, those in the BWG also improved stride length, which might further relate to a decreased risk of falling. In contrast, no changes were seen for stride time variability. For the purpose of the current study, fall risk was not evaluated specifically, but rather derived from mobility performance which is explained throughout the following sections.

6.2.3 Body mass index

Body composition of participants in the current study was reported as Body Mass Index (BMI), where body mass is expressed in relation to height. A BMI of 25.0-29.9kg/m^2 places individuals in the overweight category (Lobuono et al. 2016). Participants in the current study, with a mean BMI of 27.0±5.1kg/m^2, were classified as being overweight, which places them at risk of developing a cardiovascular disease (Lobuono et al. 2016). Treatment of cardiovascular risk factors may slow PD progression (Cereda et al. 2013). A BMI of more than 30.0kg/m^2 can potentially lead to a cardiovascular event (Lobuono et al. 2016). Even though individuals with

PD generally have a lower BMI than healthy, matched controls (Wang et al. 2015), the longer PD individuals live with the disease, the more important it becomes to maximize QoL and reduce their risk for developing metabolic complications.

Moreover, it is known that excess body weight contributes to balance impairment and unsteadiness during mobility tasks, highlighting the impact of the correlation between BMI and increased postural instability on fall risk (Wang et al. 2015). Thus, physical activity is important to decrease both cardiovascular and fall risk and, as a result, improve QoL.

In the current study, both groups improved their functional capacity, which contribute to improved cardiovascular function. In response to the intervention, the FWG improved their experiences of daily living (UPDRS II) and the BWG improved their QoL-related domains on the Parkinson's Disease Questionaire-39 (PDQ-39). These improvements highlight that the participants can more easily participate in daily tasks and by being able to do so, they avoid a sedentary lifestyle that can contribute to co-morbidities and health-care costs.

It has been reported that overweight adults older than 65 years have poorer cognitive performance than those with normal BMI (Benito-Leon et al 2013) and that obesity may accelerate age-related cognitive decline (Kirton & Dotson 2015). Participants in the current study had mild cognitive impairment, which can be associated with being overweight, ageing and disease-related impairments.

6.2.4 Motor symptoms severity

Parkinson's disease severity is most often staged according to the level of postural and gait impairments, by means of the Hoehn and Yahr (H&Y) classification system (Hoehn & Yahr 1967). This scale was used to categorized participants into mild, stage II (bilateral symptoms without balance impairment), or moderate, stage III (postural instability and need assistance to recover from the pull test), PD (Goetz et al. 2008). All participating individuals could ambulate independently, which was defined as the ability to move about without physical assistance of supervision of another individual (Holden et al. 1986). In response to the intervention, the BWG improved their H&Y stage. Considering the definitions of the H&Y staging, improvement from stage III to II may suggest improvement in either stability or balance measures in response to the BW training program. Despite the fact that decreased turning angle and DT interference of %DS phase reflect impaired stability in the BWG, higher turning velocities and improved DT interference of %DS variability illustrate improved postural control, which may relate back to improved H&Y staging.

The MDS-UPDRS part II and III are used in combination with the H&Y stage, to give a more specific representation of disease-related motor symptoms and experiences of daily living.

The MDS-UPDRS Part III assesses the severity of disease-related motor symptoms. According to this scale, the average annual progression of motor symptoms is approximately 2.2 points (Alves et al. 2008). In contrast, a recent study by Ellis et al. (2015) reported that UPDRS III scores show marginal to no change over a 12-month period. The aforementioned study adjusted their findings for age, levodopa dosage, fall history, comorbidities and H&Y status to conclude that one can expect an increased score of 1.8 on UPDRS motor severity within 18 months, but a 2.5 point increase after two years (Ellis et al. 2015). In response to the intervention, the FWG and BWG groups improved UPDRS III scores by 4.6 and 4.2 points, respectively. Taken together, eight weeks FW or BW gait retraining program can effectively delay a two-year regression in motor symptom severity. Moreover, disease severity is associated with gait speed, which also improved in both groups and strengthens the impact of the current intervention on QoL.

Previous studies on similar PD individuals reported UPDRS III scores of 36.8±18.4 and 40.7±14.8, which are both in line with (Goetz et al. 2008) and worse than current findings (Horváth et al. 2015). In response to the training programs, both groups improved their motor scores, showing how physical activity can improve and delay disease severity reflected through motor symptoms. At post-testing, there was no statistically significant difference between groups; however, there was a huge practical significant difference presented in which the BWG had lower scores than the FWG. This difference can possibly be attributed to changes in the individual motor symptom severity scores.

Both groups improved their bradykinesia scores in response to the intervention with changes of 23.6% in the FWG and 12.2% in the BWG. Interestingly, bradykinesia is negatively associated with cognitive flexibility (Schneider et al. 2015). Despite changes in bradykinesia scores in the current study, global cognition remained unchanged. Additionally, the BWG improved their tremor scores by 12.7%, while the 45.2% worsening rigidity of the FWG contributed to a between-group difference in rigidity scores at post-testing. These outcomes collectively could have attributed to the between-group difference seen in disease severity scores at post-testing.

With regards to rigidity, only a small proportion of each session was set aside for flexibility exercises. Despite these exercises, the FWG significantly worsened their rigidity scores, which possibly reflects the natural course of the disease and is further supported by the huge practically significant difference for the worsened disease severity scores of the FWG at post-testing.

Although the natural course of the disease should also have affected the BWG, their rigidity scores remained unchanged. It is possible that the nature of BW combated this inevitable decline in muscular stiffness. As the foot is placed behind the body with BW, hip extension is facilitated (Hoogkamer et al. 2014) to thereby actively stretch the hip flexors during walking. Also, hamstring flexibility has been reported to increase after a four-week BW intervention for young athletes with lower back pain (Dufek et al. 2011). Moreover, in response to fear of falling and task-specific visual restrictions, BW participants often twisted their bodies and heads every few meters to view their walking path. These motions were not made with FW and could also explain between-group differences in rigidity at post-testing.

6.2.5 Global cognition

Cognitive impairment was assessed with the Montreal Cognitive Assessment (MoCA). Cognitive dysfunction can present with impaired executive function, working memory, attention, visuospatial function as well as decreased DT abilities (Schneider et al. 2015).

Global cognition is an important factor to consider in PD, as it can be experienced even during the early disease stages and becomes more prevalent as the disease progresses. Up to 57% of individuals with PD may show evidence of cognitive impairment after 3.5 years of diagnosis (Alves et al. 2008). This was also seen in participants in the FWG and BWG, who had a disease duration of 7.0±6.0 years and 5.0±3.0 years and MoCA scores of 24.3±2.1 and 23.1±2.8, respectively. From these findings, participants were in the mild cognitive impairment category that range from 19.0 to 25.2 on MoCA (Hoops et al. 2009). There were however no changes in MoCA scores towards the post-testing.

As executive function is only one of a variety of cognitive domains assessed with MoCA, future studies should include an alternative cognitive test that assesses a wider perspective of the exercise program on cognitive performance, - perhaps a walking Stroop test. Nevertheless, DT performance in the current study is a good indication of executive functioning. Situations where one performs a secondary task while walking is evident in many activities of daily living (ADL). Common examples include simultaneously crossing a street and watching traffic, carrying groceries or talking to someone. While performing a secondary task, individuals with PD generally present with increased gait asymmetry (GA), compared to normal, single task, walking as well as compared to healthy, elderly fallers (Yogev et al. 2005). This indicates that, with the exception of clinical symptoms, the regulation of gait may rely on cognitive function and highlights the contribution of executive dysfunction on fall risk during DT. Section 6.4.3 elaborates on DT abilities of participants in the current study.

6.2.6 Depressive mood

Up to 68.1% individuals with PD are affected by depression which highly affects their QoL (Chagas et al. 2013). The Patient Health Questionnaire (PHQ-9) was used to assess depressive mood in PD. The PHQ-9 has a cut-off score of 9 to identify depression in PD (Chagas et al. 2013). At baseline, participants in both groups were categorized as having mild depression, indicated by a PHQ-9 score of 5-9 (Kroenke et al. 2001). Even though changes in response to the intervention were non-significant, the FWG (5.2±3.3) and BWG (5.1±5.2) had borderline mild depression post-testing. Mental well-being and self-reported balance abilities are related in PD and, if impaired, negatively influence QoL (Šumec et al. 2015). The plateau in depressive mood and balance confidence found over the eight weeks in the current study is in line with subjective measures of disease-related QoL which were also maintained. As these three subjective measures are interconnected, the maintenance thereof is important for PD individuals to avoid social isolation and the relating consequences.

6.2.7 Freezing of gait

Freezing of gait (FOG) is the sudden, episodic inability to generate effective forward motion in PD in which normal, voluntary movement is interrupted (Snijders et al. 2010). Freezing episodes are mostly associated with later disease stages; however, up to 26% of individuals with early PD experience FOG (Moore et al. 2008). In line with the current study where participants had early PD (H&Y II-III), 78.6% of the FWG and 66.7% of the BWG were classified as freezers at baseline, as assessed with the Freezing of Gait Questionnaire (FOG-Q). Moreover, Snijders et al. (2010) proposed that PD individuals with cognitive impairment present with a higher risk of falls and freezing than those without cognitive impairment. As participants in the current study were mildly cognitively impaired and consisted of a high proportion of freezers, their risk of falling is evident. Despite the drop in the proportion of freezers in the FWG and BWG to 71.4% and 60.0%, respectively, the intervention did not yield significant changes in FOG outcomes.

Freezing of gait is often experienced during usual walking, presenting as the inability to continue moving forward, when movement is initiated, during turning, when negotiating narrow spaces and obstacles, when reaching a target or when performing two tasks simultaneously (Hausdorff et al. 2003; Khobkhun et al. 2014). Of these triggers, walking, turning and DT abilities were investigated in the current study. Literature suggests that the *en bloc* turning technique utilized by PD individuals contributes to FOG while turning (Earhart & Falvo 2013; El-Gohary et al. 2013). While performing a DT, attention needs to be divided and is frequently directed away from walking. The imposed motor disruption may result in FOG (Beck et al. 2015). Section 6.4.2

and 6.4.3 respectively elaborate on turning and DT abilities of participants in the current study. Keeping in mind that FOG often leads to falls, FOG triggers can contribute to fear of falling, and thereby cause social isolation and decreased QoL.

6.2.8 Medication

Participants in the current study did not alter their medication usage over the study period (Appendix C). Both groups were tested at a similar time after their previous medication dosage, which did not differ between the two testing sessions. It is therefore assumed that results from the current study are not affected by changes in anti-Parkinson medication dosages. In this light, it was recently reported that gait pattern is most stable at 165 minutes after levodopa intake (Paker et al. 2015). Considering that participants were tested more or less 180min after medication intake, gait variability outcomes might have been influenced by the timeframe of previous medication intake. Walking performance could show fluctuations in response to medication intake.

Anti-Parkinson medication has shown to improve some, but not all PD-related impairments. For example, motor deficits can be improved with anti-Parkinson's medication, whereas turning (Hong & Earhart 2010; Curtze et al. 2015) and balance (Song et al. 2012; Curtze et al. 2015) deficits are not affected by medication, especially during the later disease stages (Earhart & Falvo 2013). Moreover, it appears that PD medication does not reduce the incidence of falls (Allen et al. 2010). As anti-Parkinson medication becomes only partially effective as the disease progresses (Earhart & Falvo 2013), non-pharmacological strategies to improve or maintain disease-related impairments are evident.

Seeing that both the FWG and BWG improved their motor symptom severity scores, an eight-week gait retraining program can delay the inevitable increase in medication usage. Additionally, the FWG improved their turning technique, which generally is unaffected by anti-Parkinson medication. It was also reported that dopamine medication rather influences spatial (stride length) than temporal (gait speed, cadence, time variables) gait parameters (Lord et al. 2011). In the current study, both the groups improved their gait speed. Additionally, the BWG improved stride length, cadence and gait cycle time. Taken together, this suggests that both, but particularly the BW gait retraining program, yielded improvements in gait variables that are beyond what can be achieved by dopamine medication. Sections 6.4.1 and 6.4.2 respectively elaborate more on spatiotemporal and turning performance of participants in the current study.

6.3 Intervention

6.3.1 Rating of perceived exertion

The 0-10 Borg RPE scale was used to obtain a rating of participants' perceived exertion at the end of each session. The weekly average RPE rating was compared between groups and findings showed that the FWG consistently scored a higher RPE than the BWG (Appendix A3). These findings are in contrast to what was expected, as previous reports on healthy individuals states that BW or running requires increased energy consumption (Terblanche et al. 2005; Woo et al. 2009). There are a few possible explanations for this finding. On the one hand, BW is a novel activity to participants. Considering that PD individuals have backward instability (Hackney & Earhart 2009; Peterson & Horak 2016), it is possible that the BWG attempted to minimize their fall risk by lowering the intensity of the exercise activities to a level with which they felt safe with. On the other hand, FW is a well-known task, enabling the FWG to more easily push themselves to exercise at higher intensities. Also, the FWG did not need a familiarization period like the BWG and could therefore focus more on refining the task at hand. According to a theory proposed by Fitts and Posner (1967), the BWG could have been in the cognitive stage of motor learning and the FWG most likely in the associative stage.

6.3.2 Intrinsic motivation

At the end of the intervention, participants of both groups were asked to complete a short version of the Intrinsic Motivation Inventory (IMI, Appendix K) to assess their self-reported degree of motivation while performing the training tasks. This questionnaire can be divided into five different domains relating to motivation: interest and enjoyment, perceived competence, effort and importance, pressure and tension as well as value and usefulness, where higher scores indicate better motivation (Khalil et al. 2012). Even though pressure and tension is negative predictors, scores were inverted in the analyses. Intrinsic motivation specifically is measured with the interest and enjoyment domain, whereas the other four domains can be considered as predictors of intrinsic motivation. In the currents study, there were no between-group differences for any of the four domains. This finding suggests that despite the differences in task specificity, i.e. FW or BW, both groups had similar motivation and perception following the eight weeks. This suggests that findings from the respective groups were as a result of internal factors rather than external rewards (Mcauley & Tamrnen 1989).

6.4 Findings with regards to research questions

The following sections summarise the findings of the forward and backwards gait retraining programs' influence on mobility, functional capacity, balance confidence and quality of life as set out by the research objectives in Chapter 2. A summary of the main results is provided in Table 6.1.

Table 6.1: Summary of the significant changes found in variables of the study

Variable	Forward walking group	Backward walking group
Single task conditions		
Walking velocity	↑	↑
Turning velocity	↑	↑
10m Walk test duration	-	↑
Gait cycle time	-	↑
Stride length	-	↑
Cadence	-	↑
Stride length variability	-	↓
5-Times-Sit-to-Stand duration	↑	-
Timed-Up-and-Go duration	↑	-
Turning angle	↑	-
Dual task conditions		
Timed-Up-and-Go duration	↑	-
Turning angle	↑	-
Dual task Cost		
Percentage double support variability	-	↑
Percentage double support	-	↓
Swing time gait asymmetry	-	↓
Stride length	↑	-
Secondary Outcome variables		
Motor symptom severity	↑	↑
Functional capacity	↑	↑
Quality of life	-	↑
Activities of daily living	↑	-

6.4.1 Objective 1: Comparing gait parameters under single task conditions (Chapter 3, Article 1)

Ellis et al. (2015) stated that that the natural trajectory of walking-related activity limitation is the most potent indicator of evolving PD disability over time, suggesting that routine assessment of walking (like with the i10mWT) and rehabilitation is crucial. In the current study, gait parameters were assessed by using an instrumented i10mWT. The main findings after the eight-week forward and backward gait retraining programs were improved gait speed and stride velocity, expressed as percentage stature (SV), in both groups. Additionally, the BWG improved their i10mWT duration, cadence, stride length (SL) and gait cycle (GC) time and worsened SL variability. None of these measures differed significantly from the FWG at post-testing.

Walking speed is considered an indication of mobility for PD individuals of all severity stages (Hass et al. 2014). Gait speed is a function of SL and cadence (Danoudis & Iansek 2014). In a stable environment, walking at a self-determined speed with minimal attentional demands, is controlled by the basal ganglia through its connections to the frontal cortical regions (Danoudis & Iansek 2014). It is suggested that these connections are responsible for the maintenance of a stable SL:Cadence relationship, which in turn allows for automaticity in self-selected gait speed (Danoudis & Iansek 2014). Findings from the current study suggest that even though both FW and BW gait retraining were successful to improve gait speed and SV, only the BWG restored their SL:Cadence relationship, reflecting improved automaticity during straight walking at self-selected walking speeds. Nevertheless, from a large longitudinal study on gait speed of elderly individuals, an average annual decrease of 0.03m/s, compared to 0.02m/s, was associated with twice the risk of mortality, irrespective of gait speed at baseline (Ellis et al. 2015).

Considering gait characteristics, recent studies noted substantial differences between matched TD and PIGD PD individuals. Individuals with TD symptoms generally have faster walking speeds, longer SL, shorter TUG duration and faster turning velocities as well as more left-right GA, more severe FOG and higher bradykinesia scores compared to the PIGD group (Herman et al. 2014; Gordon et al. 2016; Peterson & Horak 2016). Contrasting to these relationships, other studies concluded that PD individuals with PIGD have faster disease progression and higher risk of freezing (Moore et al. 2008) and bradykinesia (Schneider et al. 2015). Considering these findings, it is important to note that participants categorized as having PIGD had higher UPDRS total scores with similar motor severity scores (Herman et al. 2014a) and longer disease duration (Gordon et al. 2016) than those with TD, which may also have contributed to between group differences. Despite these relationships between PD-subtypes and mobility performance, the

current study did not investigate the impact of PD-subtypes on outcome measures to support findings. Future endeavours should keep this limitation in mind.

Furthermore, perceived balance confidence (ABC), depression, global cognition and mobility (from the PDQ-39 domains) as well as motor function (UPDRS III) have previously been found to correlate with SL and gait speed (Curtze et al. 2016). Even though balance confidence, depression and global cognition were maintained over the eight weeks, both groups improved in their motor symptom severity scores, which relates to improved gait speed. Additional improvements were seen in the BWG for H&Y score and the mobility domain of the PDQ-39 which also relate to their improved SL. Furthermore, anti-Parkinson medication rather influences spatial (stride length) than temporal (gait speed, cadence, time variables) gait parameters (Schaafsma et al. 2003; Lord et al. 2011; Curtze et al. 2015). Taken together, it seems that an eight-week BW gait retraining program is beneficial to improve spatial and some temporal gait parameters that are unaffected by anti-Parkinson medication.

It is thought that BW may utilize a similar mechanism than that of external cues to induce gait improvements. PD is characterised by disrupted basal ganglia-supplementary motor area (SMA) interaction. The SMA is inhibited when the basal ganglia runs movement sequences to completion. This does not occur with novel or complex tasks, but only with well learned movement sequences. External cues bypass this loop to enhance movement preparation for each sequence. Training that utilizes high levels of attention, especially those that require a mental representation of the activity and conscious focus on gait, results in similar findings to visual cue training as they make use of similar mechanisms that bypass the basal ganglia (Morris et al. 1996). Considering that a mental representation of lower limb placement during BW consistently requires high levels of attention and conscious control, this neural mechanism may be related to additional improvements seen in SL and cadence of the BWG. Other than these improvements in the BWG, SL variability increased.

Gait variability has become a practical assessment of how well individuals with PD control their gait and can be used to identify pathology (König et al. 2016). Gait variability therefore gives therapists an indication if walking rhythmicity is disturbed. Considering that, unlike SL, SL variability is dopamine-resistive, neurophysiological mechanisms other than the typical dopaminergic pathways may be involved (Thevathasan et al. 2012). However, it should be considered that more research is still needed to understand the relationship between parameters, how each parameter responds to pathology and the specific neural pathways involved with each

parameter (König et al. 2016). Besides the possibility that the increase in SL variability is a compensatory strategy, a few possible reasons for this finding are listed below.

Firstly, healthy populations apparently have a U-shaped relationship between SL variability and gait speed, indicating that SL variability is at its highest during slow and fast gait speeds and only partially affected during preferred gait speed which is generally reflective of the most mechanically and metabolically cost effective pace for an individual (Danion et al. 2003; Frenkel-Toledo et al. 2005). It is therefore possible that the participants in the current study may have walked at a fast pace and not at a comfortable pace, as per instructions, which may also explain their fast gait speed compare to other PD studies with a similar age and PD level. Therefore, the results show a linear relationship between SL variability and gait speed, which may reflect one arm of the U-shape curve.

Secondly, strength control or muscle activation is variable in PD, which plays a role in the control of postural reflexes and ambulation (Baltadjieva et al. 2006; Wu et al. 2015). Therefore, it is possible that a variation in the production of force may be the reason for increased SL variability. Individuals with PD use inappropriately scaled dynamic muscle force during movement (Wu et al. 2015). Thus, BW may have increased muscle activation and strength, as was shown in healthy individuals (Woo et al. 2009; Blazkiewicz 2013; Lee et al. 2013); thereby improving gait speed and SL, yet the control of force production is still variable in PD, reflecting as SL variability. Variability in SL can be seen as a pathological sign as it is linked to postural control (König et al. 2016). Therefore, SL variability should increase with higher H&Y (disease severity) stages. However, the BWG was the only group that significantly improved their H&Y stage, hence this does not explain the study's findings. Instead, a likely explanation is that the faster gait speeds resulted in postural instability, which may have contributed to SL variability as the participant tried to account for these balance instabilities.

Thirdly, an increase in SL variability may suggest a reduction in rhythmicity or automaticity. The mechanism involved in rhythmic stepping requires minimal attention in healthy individuals, and therefore changes in SL variability and GC variability are often not found during high attentional demands (Beauchet et al. 2005). However, this might differ in PD individuals who struggle with performing learned motor skills automatically (Nieuwboer et al. 2009; Wu et al. 2015). Specifically, a decreased SL is an example of motor automaticity deficits in PD (Wu et al. 2015). Therefore, one possible explanation for the increase in SL variability in the BW group is that they had to pay more attention during walking, possibly due to an increase in gait speed, which meant a disruption in postural control or even having to do a gait task in a forward direction instead of backwards. Moreover, as gains in spatiotemporal parameters are relatively

new to the BWG, the regulation thereof has not yet been established (Wuehr et al. 2013). As BW was a novel task for participants, a large proportion of the sessions was used for familiarization, whereas the FWG did not need a familiarization period. This is especially noteworthy as Nieuwboer et al. (2009) highlighted that PD individuals have slower learning-rates than healthy individuals. Whether SL gait variability can be decreased proportionally to SL improvements with more than eight weeks training, is yet to be determined.

Lastly, age and pathology are also related to increased variability (König et al. 2016), where more variability in all gait parameters suggests a more deteriorated walking pattern and instability. However, this might not always be the case. It is possible that, depending on the gait parameter, both more and less variability could be perceived as detrimental to the overall gait pattern. For instance, in PD an elevated variability is typically associated with unstable patterns (such a seen with stride time), while low variability could suggest more rigidity or less flexibility and adaptability in movement as seen with step width and possibly stance time (König et al. 2016). In addition, it has been found that preferred walking patterns do not necessarily produce reduced gait variability in healthy individuals (Danion et al. 2003; Frenkel-Toledo et al. 2005). Consequently, variability during walking is essential for effective motor performance and it is possible that an optimal level of variability may exist depending on the individual, context and/or task (Todorov & Jordan 2002; Stergiou et al. 2006; König et al. 2016). Furthermore, gait variability differs depending on the combination of spatial and temporal variability from SL and cadence (Danion et al. 2003). Based on the information above, direct comparison between different populations, or even within different subtypes of PD may be difficult. Moreover, differences are even present when expressing SL variability as an absolute or relative value (Danion et al. 2003).

Although mechanisms for responses to BW gait retraining are scarce, results at post-testing of the current study can be compared to spatiotemporal values reported for healthy elderly and PD individuals as well as to findings from previous gait retraining studies in PD and on BW for other neurological conditions.

Compared to healthy elderly individuals, participants in the current study had similar gait speed (Oberg et al. 1993; Hollman et al. 2011), similar GC time (Salarian et al. 2004; Frenkel-Toledo et al. 2005; Hausdorff et al. 2007), intact cadence (Canning et al. 2006; Almeida & Lebold 2010; Bryant et al. 2011; Hollman et al. 2011), shorter SL (Toosizadeh et al. 2015; Hollman et al. 2011) and worse SL variability (Hollman et al. 2011). Even though SL values approached that of healthy individuals, it seemed that the presence of PD-related symptoms still restricted normal

age-matched SL. Considering that SL is the fundamental problem underlying gait hypokinesia in PD and that the SL:Cadence ratio was improved in the BWG, it could be suggested that BW is effective in restoring or delaying the onset of the characteristic PD shuffling gait pattern. Compared to other PD individuals who were mostly similarly aged and had comparable disease severity and duration, participants in the current study had more improved gait speed (Yang et al. 2008; Toosizadeh et al. 2015; Paker et al. 2015), similar GC time (Salarian et al. 2004; Frenkel-Toledo et al. 2005; Hausdorff et al. 2007), lower cadence (Yang et al. 2008) and longer SL (Peppe et al. 2007; Yang et al. 2008; Roiz et al. 2010; Nanhoe-Mahabier et al. 2011; Toosizadeh et al. 2015. A recent study however reported on PD individuals that performed better than participants in the current study for all gait measures, possibly due to having substantially lower disease severity scores (Elshehabi et al. 2016).

Previous FW treadmill training studies in PD have shown improvements in gait speed and SL (Miyai et al. 2000; Pohl et al. 2003; Herman et al. 2007; Bello et al. 2008; Frazzitta et al. 2009). In contrast, Toole and colleagues (2005) did not find improved gait speed after six weeks of treadmill training. These studies however were either short term, compared different types of interventions, used body-weight support or did not have a control group. It has also been suggested that gait variability improves with treadmill training especially due to the external pacing provided; however, inconsistent findings are reported (Herman et al. 2007; Tseng et al. 2015; Hollman et al. 2016). A recent review on treadmill training studies concluded from ten studies that gait speed generally improves with treadmill training; whereas SL and cadence generally do not (Mehrholz et al. 2016). Taken together, an over ground BW gait retraining program can be an effective strategy to induce additional spatiotemporal improvements to that of treadmill training.

Previously, an eight-week multi-directional treadmill gait and step retraining in PD showed superior results for gait speed, SL and cadence compared to a non-exercising control group (Protas et al. 2005). Also, a 12-week home- and treadmill-based training program that compared balance and multi-directional step training with a conventional lower-limb strength training program, improved gait speed in both groups, but the gait and balance group also improved SL and balance confidence (Shen & Mak 2014). The aforementioned study also implemented augmented feedback to the gait and balance training group, which could have influenced their outcomes and possibly explain differences in balance confidence outcomes compared to the current study. A more recent study compared FW treadmill gait retraining on FW and BW gait parameters in PD and reported improved gait speed & SL for both walking directions after twelve weeks of training (Tseng et al. 2015). Compared to these treadmill training studies,

improved gait speed in the FWG suggests that over ground gait retraining can also be effective for improving gait speed.

Despite the fact that BW gait retraining specifically has not been investigated in PD, other neurological conditions have received some attention with BW. Over the past decades, over ground and treadmill BW gait retraining in stroke individuals have shown to be effective for improving gait speed and SL (Yang et al. 2005; DePaul et al. 2011; Michaelsen et al. 2014). Also, BW treadmill training improved the walking velocity and SL of children with cerebral palsy (Kim et al. 2013). Although neurological conditions such as stroke and cerebral palsy have distinct pathologies from PD, the current results illustrate that similar spatiotemporal improvements can be found with BW gait retraining in PD. Moreover, this study was the first to investigate over ground BW specifically and findings illustrate that such a training regimen is an effective strategy to improve impaired gait parameters in PD.

Regarding the inconsistency of findings and limitations in the respective gait retraining studies, it is not clear whether treadmill training is superior to over ground training for PD individuals, especially as studies on over ground gait retraining in PD are scarce. Findings from the current study illustrate that over ground gait retraining in PD can indeed be effective in improving PD gait speed. Moreover, BW gait retraining can assist in improving PD-related deficits in their SL:Cadence ratio.

Taken together, despite improvements in some gait domains with BW, the BWG still had impaired coordination that is reflective of walking instability (James et al. 2016). Consequently, rehabilitative strategies that improve coordination and stability of movement should also be kept in mind when BW gait retraining is used in practice. Considering that limitations in walking abilities are the most pronounced factor that influences PD disability over time and that gait speed can decrease from 1.1m/s in PD individuals with H&Y stage I to 0.8m/s for those with H&Y stage III (Hass et al. 2014), the improvement of gait speed seen in both the FWG and BWG was sufficient to delay the inevitable onset of mobility disability. Moreover, changes in gait speed of both groups are in line with the 1.2m/s that is necessary to negotiate crosswalks (Hollman et al. 2011), allowing participants to continue with social and community interaction to thereby maintain QoL.

6.4.2 Objective 2: Comparing postural transitions and turning under single task conditions (Chapter 4, Article 2)

In the current study, postural transitions and turns were assessed with an instrumented 5xSTS and TUG test. Transitional movements like moving from sitting to standing, standing to sitting and turning are important behaviours that are performed repeatedly on a daily basis. Therefore, sufficient ability to perform transitional movements is essential for safe mobilization.

a) Postural transitions

Postural transitions refer to the ability to move from a sitting to standing position and vice versa. The total duration to complete the iTUG and i5xSTS was used as an indication of functional mobility. In the current study, the FWG improved both their i5xSTS and iTUG duration.

At baseline, there was a significant difference in i5xSTS duration, where the FWG performed worse than the BWG. This variable is possibly reflected by a strong trend towards increased variability in SL at baseline in the FWG, which yielded a large practically significant difference. Gait variability generally reflects impaired internal regulation of neural control (Lord et al. 2011). Moreover, the FWG had worse rigidity scores than the BWG at baseline, as shown by a moderate trend, but large practically significant difference. It is well-known that rigidity restricts movement (Peterson & Horak 2016), specifically by impairing hip extension (Peterson & Horak 2016). Considering that hip extension is required for a chair transfer as well as to produce adequate SL, worse rigidity in the FWG may explain their longer i5xSTS durations. It is possible that these baseline values are related to chair transfer abilities in the FWG.

Even though motor function improved significantly in both groups, the effect of motor symptom severity on functional mobility was more reflected with improved i5xSTS and iTUG duration in the FWG than in the BWG. It is possible that the FWG with more disability at baseline, i.e. longer i5xSTS duration, had more room for improvement. This is supported by Ellis et al. (2015) who also suggested that higher functioning PD participants may show smaller changes compared to those who had greater mobility impairments. Considering other factors that may influence functional mobility performance (Hulbert et al. 2015), no changes were seen for balance confidence in either group, but both groups significantly improved their bradykinesia scores. Also, time to complete a 3m TUG is associated with gait speed (Paker et al. 2015). Even though both groups improved gait speed, only the FWG also improved iTUG time. Speed was however recorded with straight path walking while the iTUG also included other transitional movements. Considering that the FWG also improved i5xSTS duration as well as turning velocity and angle,

which are components of the iTUG, it becomes clear that the FWG additionally improved complex functional tasks; whereas the BWG improved FW straight walking, which is less complex.

Post-testing iTUG values of participants in the current study, were substantially longer than ST and DT durations reported for pre-frail adults older than 50 years (Tang et al. 2015), but was in line with DT iTUG durations reported for individuals 65-75 years old (Ullmann & Williams 2011). These findings suggest that PD impairs functional mobility under ST conditions to similar levels than what is achieved by the elderly under DT conditions. Compared to TUG durations previously reported for PD individuals under ST conditions, participants in the current study had similar durations than similarly aged early PD individuals (Paker et al. 2015); however, longer durations than individuals with substantially lower UPDRS III scores (Fernandes et al. 2015).

To summarize, the FWG improved their functional mobility; however, the BWG did not, possibly due to the nature of the two training directions. As FW training tasks simulated ADL more than that of the BW, it might explain why the FWG improved in more complex mobility measures. In line with this finding is improved experiences of daily living (UPDRS II) reported by the FWG.

b) Turning

Turning is typically hindered in PD individuals, which can lead to significant disability, falls, loss of function and independence. Turning variables were assessed during the iTUG and included turning duration, velocity and angle.

Turning velocity significantly increased in both the FWG and the BWG by 12.2% and 8.7%, respectively. Additionally, the FWG increased their turning angle by 6.2%. It is reported that peak turning velocity has been associated with improvements in balance confidence and motor function (King et al. 2012; Mancini et al. 2015). Although participants in the current study plateaued in balance confidence, both groups improved their motor symptom severity (UPDRS III) as well as bradykinesia scores, which allowed them to turn faster. Faster turns however are not always desirable in PD. An on-the-spot turn (small turn angle) at high velocity requires high levels of balance control, which is generally impaired in PD and thereby a high fall risk is induced (Mellone et al. 2016). When faster turns are accompanied by a wider turn arc (larger turn angle), overall turning ability is improved. From these findings, the FWG and BWG utilized different turning techniques at post-testing.

Turning is a complex activity as it requires high levels of coordination from the central nervous system to modify locomotor trajectory while continuing a stepping cycle and maintaining stability (Mellone et al. 2016). Compared to straight walking, turning is a much more difficult task as it requires different motor programs for each lower limb (Plotnik et al. 2005). Consequently, PD individuals can present with normal straight walking parameters, but with impaired turning abilities (Song et al. 2012; Mellone et al. 2016). It is reported that during daily activities, at least two turns are performed every ten steps (Chou & Lee 2013), suggesting that the ability to turn safely is essential for quality performance of ADL. Turning is a major cause for FOG and consequently fall risk in PD (Earhart & Falvo 2013; El-Gohary et al. 2013). In the current study, freezing status (FOG-Q) remained unchanged in response to the intervention. Consequently, objective changes in turning ability did not impact subjective assessments of the effect of gait impairments and freezing status on independence. Fall risk becomes evident while turning considering that dynamic stability is challenged as the body's centre of mass needs to be controlled over a moving base of support. Consequently, the centre of mass momentarily moves outside the base of support, possibly predisposing an individual to falls (Mellone et al. 2016). Unfortunately, fall risk was not assessed for the purpose of this study and the relationship between findings and fall risk should be carefully considered in future studies.

According to a recent review, which compared turning in PD and healthy controls, PD turning deficits originate from two hypothetical body segments and can be categorized as either perpendicular (i.e. movement deficits in the lower limbs, including increased step frequency, shorter steps and an altered turn strategy) or axial (i.e. movement deficits of the head, trunk and pelvis, including reduced segment coordination, timing and rotation as well as increased axial segment rigidity and altered posture. In addition, it is possible, but unclear, that axial deficits may drive resulting responses in the perpendicular segments, where a rigid trunk stabilizes limb motions during a turn (Hulbert et al. 2015) and in doing so, further disrupts dynamic stability during turning (Chou & Lee 2013). According to this review, most rehabilitation programs emphasize perpendicular aspects, i.e. lower extremities, and not axial segments. As this study did not include 3-dimensional movement analysis, interpretations of axial segments cannot be made. Considering that the current study focused on gait-related aspects, perpendicular deficits were emphasized, which is similar to the focus of previous work (Hulbert et al. 2015).

Although not all perpendicular aspects of turns, i.e. step frequency and step length, were assessed in the two groups, turning strategy can be deduced from the results. Individuals with PD generally perform shorter turns with smaller angles and more steps, presenting as an *en bloc* turn.

For this turning technique, rotating the head, neck and trunk simultaneously like a rigid statue is needed and multiple small steps are required (El-Gohary et al. 2013).

It is suspected that turning strategies used by the two groups differed at post-testing. The FWG utilized a more beneficial turning strategy as both turning velocity and turning angle improved. This shows that the FWG gained more control of their centre of gravity over a changing base of support when executing a turn as well as improved motor program control to switch from straight walking to turning, as shown by improved iTUG performance (Chou & Lee 2013; Cheng et al. 2014). This may be indicative of freeing more degrees of freedom, suggesting improved segmental coordination and postural stability in the FWG, and that task specific training may be more important for improved turning abilities.

In contrast, the BWG only improved turning velocity, but had similar turning angle at post-testing. As both groups improved gait speed and turning velocity, it is possible that, despite different motor programs, the control mechanisms of these two parameters are partially related (Chou & Lee 2013; Cheng et al. 2014). Hulbert et al. (2015) noted that the tighter the turn (i.e. the smaller the turn angle), the more these spatiotemporal characteristics are affected. More specifically, smaller turns at higher velocities produce a greater reduction in step length, which may be an effort to preserve postural stability (Hulbert et al. 2015). Therefore, more compensatory steps are needed to complete the turn, expressing impaired bilateral coordination that is adapted in compensation to postural instability (El-Gohary et al. 2013). This turning technique decreases the body's momentum and in turn reduces neuromuscular demands (Song et al. 2012). Taken together, the number of degrees of freedom that need to be controlled for for were reduced to allow the BWG to control their centre of mass while their weight is transferred between lower limbs during the turn (Smulders et al. 2016; Tramontano et al. 2016). Impaired stability of the BWG is further expressed with more DT interference on %DS. The aforementioned finding is explained in more detail in section 6.4.3.

Considering the novelty of BW, the BWG required constant conscious control to transfer the body backward during training. It is possible that the BWG either became accustomed to conscious control of stability, or that the training program was not sufficiently long enough to allow them to achieve the required levels of coordination for improved turning (El-Gohary et al. 2013). Therefore, the BWG presumably was in the cognitive stage of motor learning; whereas the FWG was most likely in the associative stage. In other words, a portion of the eight-week program was used by the BWG to become familiarized with BW. During this time, the FWG could focus more on refining their turning skills (Fitts & Posner, 1967).

It is generally known that PD individuals have longer turning durations, slower turning velocities and smaller turn angles than aged matched, healthy controls (El-Gohary et al. 2013); however contrasting results were found between these healthy controls and participants in the current study. Both the FWG and BWG had substantially larger turning velocities and angles at both testing points compared to values reported for PD individuals in previous studies by El-Gohary et al. (2013) and Mancini et al. (2015). The PD individuals in these studies were of similar age of those in the current study, but had much lower disease severity scores, which have an impact on turning performance (King et al. 2012; Mancini et al. 2015). Moreover, protocols used in these two aforementioned studies differed from the current protocol as they monitored turning performance of participants at home over a several days. It is reported that mobility performance under testing situations differs from that at home (El-Gohary et al. 2013). A recent study reported faster turning velocities than what was found in the present study (Elshehabi et al. 2016); however, they instructed participants (who had less severe disease severity than the current study) to turn as fast as possible, which might explain the different outcomes to comfortable speed which was used in the current study. Also, a recent study illustrated the difference in turning duration between turns to the affected and unaffected side (Cheng et al. 2014). Considering that participants in the current study were not instructed to turn in a specific direction, results are possibly not reflective of their worst performance. Previous studies on gait retraining for turning performance in PD are scarce, making comparisons to the current study difficult.

To conclude, it can be assumed that as with previous studies, BW may possibly improve executive function (Hoogkamer et al. 2014); however, the findings of this study did not support this hypothesis. This is shown by unchanged global cognition scores as well as the scarcity of improved mobility parameters under DT conditions (only DT interference on %DS variability improved). The FWG improved in turning ability but not the BWG. One possible explanation for the improvement in FWG is that turning in a FW direction might have been more task specific than the BWG. Secondly, one should consider that FW is not a new motor skill for the individuals that were included in this study, while BW could be considered a novel task. According to Fitts and Posner (1967), the BWG could have been in the cognitive stage of motor learning and the FWG most likely in the associative stage, especially considering the influence of PD on automaticity. In other words, the FWG did not need a familiarization period like the BWG and could therefore focus more on refining their turning skills. Moreover, Nieuwboer et al. (2009) highlighted that PD individuals have slower learning-rates than healthy individuals. It is therefore possible that different results could emerge with BW gait retraining interventions of

more than eight weeks. Future studies should further explore the effect of length of intervention on PD individuals.

6.4.3 Objective 3: Gait parameters, postural transitions and turning under dual task conditions (Chapter 4 and 5, Article 2 and 3)

Executive functioning plays a particular important role in the ability to walk and perform a secondary task simultaneously, by allocating attention to the competing tasks, thereby influencing fall risk (Springer et al. 2006). As the demands for attentional resources increase, the relationship between mobility and executive function increases as well. Consequently, if executive function and attention are limited, those prone to falling may be unable to divide attention appropriately between balance and gait. This places individuals at a disadvantage to confront and adapt to their environment and may lead to an increased fall risk (Springer et al. 2006).

In PD, cognitive disturbances can be experienced even during the early disease stages and become more prevalent as the disease progresses. Up to 57% of individuals with PD may show evidence of cognitive impairment after 3.5 years of diagnosis (Alves et al. 2008), with executive dysfunction being the most common cognitive impairment (Nagal & Singla 2016). Participants in the current study had much longer disease duration than 3.5 years and presented with mild cognitive impairment (MoCA). Although MoCA screens for global cognition (Dalrymple-Alford et al. 2010), executive function specifically can be assessed by simultaneously performing a motor and cognitive task.

Therefore, participants in the current study were assessed for DT interference on transitional movements, including gait, postural transitions and turning parameters while performing a secondary, arhythmic task during an instrumented i10m-walk, iTUG and i5xSTS test. Considering that participants in the current study were mildly cognitive impaired, the influence of a DT on mobility performance is expected. A recent study on ST and DT outcomes in PD showed that gait performance is consistently worse when PD individuals perform a DT and that these outcomes are insensitive to dopaminergic medication (Elshehabi et al. 2016).

It has been reported that training complex tasks that require high levels of attention, may improve attention capacity and DT abilities (Campbell et al. 2003). In the current study, the novelty of BW to participants made it a complex task. In contrast to what was expected, the BWG did not improve their DT abilities. It is possible that the addition DT during BW required too much attention and that the overload of required information disrupted DT performance more. Interestingly, the BWG consistently reported lower RPE scores than the FWG, which is

also an unexpected finding of this study. As BW was a novel activity to participants and it is well-known that PD individuals have backward instability (Hackney & Earhart 2009; Peterson & Horak 2016), RPE results suggest that the BWG could have lowered the intensity of the training sessions to a level with which they felt safe to thereby minimize their risk of falling. On the other hand, FW is a well-known task, enabling the FWG to push themselves to more easily exercise at higher intensities. According to a theory proposed by Fitts and Posner (1967), the BWG could have been in the cognitive stage of motor learning and the FWG most likely in the associative stage.

Research suggests that under DT conditions, PD individuals prioritize the additional task above postural tasks, thereby decreasing safety and increasing fall risk. It is unclear whether this holds true for participants in the current study, as performance in the concurrent task was not assessed.

The following sections elaborate on findings on DT interference on gait parameters and postural transitions.

a) Gait parameters

Improvement for DT interference was found in the FWG for SL and in the BWG for percentage double support (%DS) CoV. In contrast, negative changes were found in the BWG for %DS and swing time GA.

Compared to healthy, matched elderly individuals, PD individuals have slower gait speeds and shorter SL under DT conditions (O'Shea et al. 2002). In the current study, the FWG improved DT interference of gait speed and SL in response to the intervention. Considering the nature of DT during FW compared to BW, the FWG's training program simulated daily tasks much more accurately than the BW training program. Considering that DT interference for SL improved in the FWG, it suggests that the maintenance of SL was under more automatic control, making more attentional sources available for the DT. Furthermore, the FWG also reported improved experiences of daily living (UPDRS II scores).

In line with these findings, improved automaticity after DT training was also reported by a study that utilized cues during ST and DT gait training which improved non-cued gait speed and step length under both conditions that remained for six weeks after the intervention (Rochester et al. 2005). Previous DT gait retraining studies showed improved ST and DT gait speed and SL when walking was prioritized (Canning 2005; Fok et al. 2011) and when participants were instructed to divide attention equally (Fok et al. 2011). However, these studies however utilized the same DT during training and testing, which is in contrast to the current study despite similar outcomes.

Considering that DT interference is unaffected by PD medication, improved interference for SL in the FWG suggests that FW gait retraining is an effective non-pharmacological method to improve SL in PD. Having more automatic control over SL during DT activities will allow PD individuals to avoid a shuffling gait pattern which often leads to freezing and falling.

It is suggested that DS time variability is influenced by balance-control mechanisms (Yogev et al. 2005). As DS variability is unaffected by dopamine medication, balance control mechanisms are distinct from dopamine dependent pathways (Lord et al. 2011). Improved DS variability demonstrates a more consistent walking pattern in the BWG under DT conditions. Taken together, BW seems to affect DS variability under DT conditions through the same mechanisms that were explained for improved pace and rhythm gait domains under ST conditions.

In healthy elderly individuals (similarly aged to the current study), poorer EF and processing speed was associated with greater DS variability (Martin et al. 2013). Decreased visuospatial ability was associated with greater DS variability specifically, independently of EF and processing speed (Martin et al. 2013). Participants in the current study had mild cognitive impairment; shown with MoCA results, as well as impaired executive function specifically, shown by DT interference on gait variables. Considering that DS variability improved in the BWG, decreased interference on DS phase might be related to some improvements in executive function. Also, as vision of the walking path in BW is restricted, more visuospatial input is required. Thus, improved DS variability in the BWG can be associated with improved visuospatial abilities. However, the current study did not include a measure of visuospatial abilities to confirm this.

Time spent in DS phase of the GC generally reflects postural stability. Compared to healthy, matched elderly individuals, PD individuals spend more time in DS under DT conditions (O'Shea et al. 2002). Despite the negative association of %DS with FOG and anti-Parkinson medication usage (Lord et al. 2011; Smulders et al. 2016), neither of these two variables had an influence in the current study. Results for the FOG-Q remained unchanged over the study period and time since medication intake did not differ between groups at any time point. Consequently, it did not contributing the these results.

Longer DS phases reflect an inability to control the body's centre of mass while performing a long swing time (Smulders et al. 2016). Transition from DS phase to single-limb stance is challenging for PD individuals as they need to maintain postural stability while their weight is shifted from a stable position (DS) to a relatively unstable position (smaller base of support with single-limb stance) (Tramontano et al. 2016). Considering the novelty of BW, the BWG possibly

required more constant conscious control to transfer their bodies from DS to single-limb support. It is possible that the BWG became accustomed to conscious control of stability; however, at post-testing, the division of attention between FW and the DT became distorted and reflected that postural stability was not subconsciously or automatically maintained. Furthermore, a recent study reported that increased DS time while walking reflects perceived mobility disability (Curtze et al. 2016). However, this finding is in contrast to results of the current study, as the BWG objectively increased their DS time whilst subjectively improving their PDQ-39 mobility domain. As Curtze et al. (2016) reported on ST walking, findings under DT walking in the current study highlight the difficulty PD individuals have with performing a motor and cognitive task simultaneously.

Gait variability is generally related to increased risk of falling, but not to fear of falling (Hausdorff 2005). As the BWG improved their DS variability, they lowered their risk of falling by improving their balance control abilities (Hausdorff 2005); however, the increased %DS reflects their fear of falling under DT conditions. Unfortunately, this study did not include specific measures for risk and fear of falling. As the BWG consistently had lower weekly averages for RPE scores, it may reflect their fear of falling and show that they did not exert themselves beyond what they felt safe with. Taken together, it seems that under DT conditions, the BWG had decreased stability in compensation to fear of falling, but improved control over their walking patterns. This finding is in line with impaired stability measures under ST conditions, as explained with SL variability in the BWG. In addition to these changes, swing time GA was also affected in response to the BW intervention.

Symmetry between left and right lower extremities during walking is a reflection of the regulation of coordination between the lower limbs as well as medial-lateral stability (Yogev et al. 2007). Asymmetry is associated with FOG, but does not reflect fall status in PD (Smulders et al. 2016). There are a few possible reasons for increased swing time GA in the BWG.

Anti-Parkinson medication deprivation is known to increase GA. Considering that there was no between-group difference for time since previous medication dosage, medication deprivation did not attribute to GA in the BWG. In healthy elderly individuals, gait asymmetry is also related to limb dominance, disease, leg length discrepancies and strength imbalances (LaRoche et al. 2012). Of these factors, disease, lower limb dominance and strength imbalances could have had an influence on GA outcomes. However, the current study did not include participants' dominant side or objective muscle strength measures. Regarding the influence of disease on GA, PD individuals generally presents with increased GA, particularly under DT conditions, compared to healthy, elderly fallers (Yogev et al. 2005). Despite improvements in motor symptom severity

and bradykinesia scores in the BWG, it did not relate to improved GA under DT conditions. Even though it was not investigated in the current study, it is possible that the BW gait retraining program induced asymmetrical improvements in PD-related symptoms, as expressed by worsened GA while walking.

Recently, Peterson and Horak (2016) summarized the supraspinal control of PD locomotion. Impaired GA reflects increased cortical-spinal drive in response to reduced automatic control of locomotion (Peterson & Horak 2016). Results under DT conditions illustrate that the BW gait retraining program was not sufficient enough to induce automatic control of gait. Consequently, during the FW test, the BWG relied on cortical contributions which were used during training, again expressing the cognitive stage of learning. However, with the addition of a DT, cortical contributions were not sufficient gait could not automatically be controlled and therefore deteriorated. This suggests that basal ganglia contribution to PD gait under DT conditions, was not addressed with BW over eight weeks; however, a longer training program at higher intensities could possibly allow participants from the BWG to move from the cognitive to the associative stages of learning.

b) Postural transitions and turning

At baseline, the FWG performed significantly worse in the iTUG under DT conditions, as was reported by a previous study (Fernandes et al. 2015).

There are a few disease-related factors that may have influenced this outcome. It has been reported that those with PIGD have faster disease progression and a higher risk of freezing (Moore et al. 2008). Additionally, bradykinesia and those who have PIGD are associated with adverse cognitive outcomes (Schneider et al. 2015). Also, as explained earlier, rigidity scores were worse in the FWG at baseline, which possibly restricted their mobility. In the current study, both groups presented with mild cognitive impairment; however there were no between-group differences in MoCA scores or other descriptive outcomes at baseline. Further investigation of PD-subtypes and the effect of specific symptoms on iTUG duration may shed light on this finding; however it was not addressed in the current study.

In response to the intervention, the FWG improved their iTUG duration and turning angle under DT conditions. Improved turning angle may be a reflection of bradykinesia scores in the FWG. As the nature of the FW gait retraining program addressed the dominant complaint in the FWG, it may explain why only they improved. Moreover, the iTUG task itself is more reflective of the training tasks the FWG performed compared to the BWG. These results suggest that FW gait retraining improved automaticity of iTUG performance under DT conditions, suggesting

improved subconscious control of mobility. This ability is especially important to perform ADL effectively as many daily tasks entail a DT. To confirm this, the FWG also improved a subjective assessment of experiences of daily living (UPDRS II). Considering that the ability to perform the iTUG became more automatic while performing a secondary task, the success of FW gait retraining for PD individuals is expressed.

The addition of a DT to PD rehabilitation approaches has recently become an attractive alternatives. Although there are plenty literature interventions for ST performance, interventions for DT mobility improvement in PD are scarce. It seems though that instructions regarding the prioritization of tasks affect the outcome thereof. To the authors' knowledge, this was the first study that compared over ground BW gait retraining on DT interference of FW mobility measures. As these findings are relatively novel, comparisons to other studies are difficult and future endeavours are necessary to clarify conclusions made from this study.

6.4.4 Objective 4: Functional capacity (Chapter 3, Article 1)

Functional capacity was measured using the Six-minute-walk-test (6MWT). It is well-known that PD individuals have impaired functional capacity not only due to aging, but also the disease itself (Canning et al. 2006). As impaired physical capacity highly affects mobility and gait in PD, strategies to slow their inevitable deconditioning are important to consider.

Descriptive factors that contribute to longer 6MWT distance were listed by Enright (2003) and included height (those with longer legs, walk farther), younger age, lower body mass, gender (males walk faster than females) and higher cognitive abilities (those with impaired cognition walk slower). None of these variables differed between the two groups of the current study. Distance walked in the 6MWT can also be limited by respiratory, i.e. asthma, cystic fibrosis; cardiac, i.e. angina, congestive heart failure; metabolic, i.e. peripheral vascular disease, stroke; and orthopaedic problems, i.e. lower limb joint injuries (Enright 2003). For the purpose of this study, participants were free from major medical conditions and injuries. Considering that the sample was made up from elderly individuals who were overweight and who had mild cognitive impairment, comparisons in 6MWT distances with other populations should be carefully considered.

Clinically important improvements in 6MWT distance have been reported as 70-82m (Enright 2003; Steffen & Seney 2008) or 12-40% (Enright 2003). Even though this minimum distance was not achieved, the percentage change in response to the intervention was evident in the FWG (67m, 23.4%) and BWG (67m, 33.4%).

Distances in the 6MWT in healthy individuals can range from 400-700m (Enright 2003). Healthy individuals, aged similarly to the participants in the current study, walked 439-498m (Jones & Rikli 2002), which is much farther than what was found in the current study, reflecting the impact of PD motor impairments on functional capacity. Previous studies reported distances of 395-546 for PD individuals aged 60-70 years (Schenkman et al. 1997; Garber & Friedman 2003; Canning et al. 2006; Falvo & Earhart 2009b). In line with the current findings, previously reported treadmill training programs improved 6MWT distances in PD individuals (Cakit et al. 2007; Frazzitta et al. 2009), showing that over ground gait retraining can also be effective to improve functional capacity in PD.

Discrepancies found in distances walked in six minutes may be explained by different courses used, different instructions to participants as well as different disease duration and motor symptom severity. Despite the familiarity of the test, walking paths that require fewer turns over a longer length track allow individuals to walk farther (Enright 2003). Conversely, it has been reported that hypokinetic turning had no independent contribution to 6MWT distance (Canning et al. 2006). Due to spatial constraints, the track used in the current study was however not standardized across the three locations. Track lengths differed according to the size of the hall that was used and participants at one of the locations walked up and down; whereas the others walked in a rectangle. Nevertheless, results demonstrate the positive effect of both gait retraining programs on gait and mobility.

Previous reports illustrate the correlations between 6MWT distance, walking speed, turn velocity, and lower extremity muscle strength (Canning et al. 2006). Improved functional capacity found in the current study, is further supported by improved gait speed (FWG: 9.5%; BWG: 14.0%) and turning velocity (FWG: 12.1%; BWG: 8.7%). Regardless of these changes, no changes were found for lower extremity muscle strength via the i5xSTS test. However, it has been reported that in PD specifically, 5xSTS performance is not related to lower limb muscles strength (Duncan et al. 2011).

Considering these findings, it is clear that eight weeks of over ground gait retraining is effective for improving functional capacity in PD. In response to these changes, sedentary lifestyles can be combated, risk for co-morbidities can be delayed or decreased and QoL can be improved (Goodwin et al. 2008).

6.4.5 Objective 5: Perceived balance confidence (Chapter 4, Article 2)

The ABC scale was used to assess balance confidence and fall risk in PD (Steffen & Seney 2008). The ABC scale is a self-reported questionnaire requiring participants to rate their

confidence that they will maintain their balance while performing specific daily tasks (King et al. 2012). For balance confidence, neither the FWG, nor the BWG showed significant improvement in ABC scores. Even though participants in this study did not reach a minimal detectable change of 13% or 11% that has been previously reported for PD (Steffen & Seney 2008; Dal Bello-Haas et al. 2011, respectively), they did improve their fall risk. A cut-off score of 69% was reported to be predictive of recurrent falls in individuals with mild to moderate PD (King et al. 2012; Mak et al. 2012). Considering this cut-off score, participants of the current study were at risk of falling at baseline. After the training intervention, the FWG and BWG increased their confidence by 15.4% and 7.25%, respectively, which eliminated their fall risk. Moreover, the current sample had similar perceived balance confidence compared to a previous study that reported an ABC score of 73.6±19.3% for PD individuals that were younger with lower motor symptom severity scores (Mak et al. 2012). Also, a six-week treadmill training study in PD individuals with less severe motor symptoms similarly reported no changes in balance confidence; however their scores were substantially higher than that of participants in the current study (Herman et al. 2007). In contrast to the aforementioned and current study, Shen and Mak (2014) improved balance confidence in PD individuals after a 12-week home- and treadmill-based multi-directional step training program, compared to a conventional lower-limb strength training program. However, improvements in balance confidence may be due to the addition of augmented feedback to the gait and balance training group.

6.4.6 Objective 6: Disease-related quality of life (Chapter 3 and 4, Article 1 and 2)

For PD individuals, motor symptoms such as rigidity, bradykinesia, gait and postural instability in combination with depression and global cognition have a major impact on QoL. In addition, if one considers the International Classification of Functioning, Disability and Health model, then the PDQ-39 has been shown to correlate negatively with participation in daily activities (Ellis et al. 2015).

The effect of the gait retraining intervention on PD-related QoL was assessed by means of the PDQ-39 to determine mild treatment effects on different PD-related domains (Stegemöller et al. 2014). These domains included mobility, ADL, emotional well-being, stigma, social support, cognition, communication and bodily discomfort. Ellis et al. (2015) used the PDQ-39 to describe the natural trajectory of ‘restriction to participate in daily life’ in PD individuals over a two-year period using a prospective, longitudinal approach. They found that there was no change in PDQ-39 scores up to18 months and only noticed an increase (i.e. worsening) in scores from 18 to 24 months. In the current study, the total PDQ-39 scores did not improve over time; however, the BWG showed improvements in all eight individual domains. In other words, due to the natural

regression in QoL scores from 18 to 24 months, one would not be able to objectively say the FWG maintained QoL, whereas the BWG definitely showed improvements. Taken together, within eight weeks, a FW or BW gait retraining program can effectively delay a two-year regression in disease related QoL. Moreover, gait and postural control are known to predict QoL, morbidity and mortality in PD (Ellis et al. 2015). Despite the results for self-reported QoL, both groups improved their gait speed, which is an objective measure and highly influences QoL.

Participants of the current study scored substantially lower than previously reported total scores of 48.1±13.4 (Tamás et al. 2014) and 50.2±33.6 (Sabari et al. 2015). Considering previously reported values for H&Y stage II PD individuals of similar age and disease duration than the current sample (Jenkinson et al. 1997), only the mobility domain was lower in both groups during pre- and post-testing. Over time, only the BWG improved in the ADL and emotional well-being domains to below these previously reported values. Considering the reported values for H&Y stage 3 PD individuals of similar age and disease duration to the current study (Jenkinson et al. 1997), the same trend was seen in all the domains for the BWG, with the exception of the ADL domain, where the FWG also improved their scores to below these values. A large study on PD individuals of similar age and disease duration, but a wider range of disease severity stages, reported lower scores for the individual domains (Stegemöller et al. 2014).

Comparing results of the individual PDQ-39 domains to previously reported values, participants in the current study had worse scores in most domains, but better scores in the mobility and emotional well-being domains as well as conflicting results for the ADL and stigma domains (Stegemöller et al. 2014; Tamás et al. 2014; Sabari et al. 2015). Even though disease duration and H&Y stage were similar (Sabari et al. 2015), discrepancies in findings may be due to age differences (Tamás et al. 2014); however more participant descriptive characteristics were not reported. Despite the discrepancies between the current and previous studies, it seems that the mobility domain specifically was improved in the BWG to values below what has been reported previously.

In contrast to present findings, a previous six-weeks treadmill training study on PD individuals (similar age and disease duration, slightly better disease severity) improved their PDQ-39 total score from 32.0±23.1 to 22.0±14.3 (Herman et al. 2007). It seems that the treadmill training program was more beneficial than the current over ground training programs for total scores; however Herman et al. (2007) did not report on the individual domains, which changed significantly in response to eight-weeks over ground BW in the current study. In response to an

aerobic treadmill training program of a more recent study on PD individuals of similar H&Y stage, only the ADL domain improved (King et al. 2013).

Additionally, the MDS-UPDRS part II was used to assess disease-related motor experiences of daily living (Goetz et al. 2007). In the current study, only the FWG significantly improved their UPDRS II scores. It can be suggested that the nature of FW more closely relates to a variety of real life situations or activities compared to BW, highlighting the importance of specificity of a training program. Scores of both groups at post-testing were similar to a previous study on PD individuals of similar age and disease duration (Rodriguez-Blazquez et al. 2013). In contrast, a different study on slightly younger PD individuals with slightly longer disease duration than the current study reported a UPDRS II score of 17.0±8.6 (Horváth et al. 2015). This score is similar to what the FWG had at baseline; however, is much higher than what participants in both groups of the current study scored after the intervention.

Taken together, conflicting results for PDQ-39 total scores as well as individual domains exist. Considering the findings from training studies, it seems that over ground BW rather than FW is more beneficial than FW treadmill training for subjective QoL domains. Moreover, outcomes of the BWG showed that the natural decline in PDQ-39 scores can be combated with an eight-week BW, compared to a FW gait retraining program that maintained QoL domains. Nevertheless, the FWG improved their experience of daily living (UPDRS II), which is also a subjective assessment of QoL. These findings suggest that gait retraining may have an impact on subjective views of QoL and daily experiences, which were objectively shown through improved functional capacity and gait speed in both BW and FW groups.

6.5 Study limitations and Future studies

This study included a relatively small sample size and the authors acknowledge the effect thereof on the power– especially for variables where participants can be further divided into sub-types (i.e. freezers, TD individuals, most affected side, etc.). Unfortunately, due to time, logistical and geographical constraints as well as limited financial and human resources, it was difficult to include more participants. Considering the limits set by the participation criteria, a wider variety of demographic characteristics may make generalizability of the results easier.

Even though men and women were evenly distributed between the two groups, 65.5% of the total sample was men. Therefore, the generalizability of the results to a specific gender should be carefully considered.

This study did not include a non-exercising control group. Although training in PD has been extensively research, there is no consensus on the optimal rehabilitation modality. Therefore, comparison studies are of importance. Being able to compare FW and BW gait retraining to no intervention might have shed more light on the effect and addition of either training programs – especially for those findings that changed similarly for both the FWG and BWG. Therefore, a limitation of the study is thus that the data cannot be generalized and conclusions are only based on FW compared to BW in the sample I used.

As the nature of the FW gait retraining program addressed the dominant complaint in the FWG, but not the BWG, future studies should also include a test that is reflective of BW abilities.

Regarding the inherent variability between PD sub-groups, there are discrepancies in the literature on which protocol is best to measure variability. For example, Galna et al. (2013) reported the highest reliability for gait variability in PD with at least 30 steps; whereas König et al. (2016) argued that at least 50 steps are required to accurately measure gait variability. The average number of steps in the current study was 44, which falls in between the recommendations of these two studies. Consequentely, future studies should address consensus on measuring gait variability in PD, especially under DT conditions.

Unfortunately, it was not one of the aims of this study to include measures of fall status and fear of falling to support findings from this study. Future studies should also include these measures to determine their association with fall risk measures.

Only spatiotemporal parameters were measured, which have recently been reported as not being sensitive enough to disease severity. The addition of kinetic measures as well as 3D motion analysis can be more beneficial for biomechanical interpretation of the results (Albani et al. 2014).

Despite the novelty of BW, this study did not include a familiarization period for the BWG. As this could have influenced motor learning, the inclusion of a familiarization period should be considered by future studies. Also, longer term investigations of BW gait retraining in PD, with more frequent assessments, should be performed.

By walking on a treadmill, walking speed is predetermined and maintained rather than voluntarily controlled. This is useful for individuals with PD as their reduced neural activity in the cortical motor areas of the brain may limit their ability to exercise at a self-selected high frequency and that external control of intensity may be beneficial to them (Earhart & Falvo 2013). The current study made use of over ground gait retraining, which is relatively scarce in

terms of availability current literature. Even though over ground gait retraining has shown beneficial results, future studies should compare treadmill with over ground gait retraining in PD, especially the use of BW treadmill training.

A recent study illustrated the difference in turning duration between turns to the affected and unaffected side (Cheng et al. 2014). Unfortunately, turning direction was not investigated with the protocol of this study. Future studies should keep in mind to either assess both turning directions, or to instruct participants to turn towards the most, or least affected side, as this may influence turning performance. Also, the current study did not assess step number during a turn. Future studies should include these aforementioned considerations to better assess participants' turning technique.

Future studies should keep in mind that lab-based procedures reflect higher peak turning velocities than longer term, home-based methods (El-Gohary et al. 2013).

The effect of medication on mobility performance is well reported. Participants in the current study were tested in the 'on-state' of medication usage. While this represented the mobility changes during the 'on-state', it may have underestimated the mobility changes during the 'off-state'. Consequently, mobility impairments may have reflected more during the 'off-state'. Future studies should also obtain the necessary information to calculate participants' levodopa equivalent dosage.

6.6 Application of findings

Both forward and backward over ground gait retraining for eight-weeks can be beneficial for improving functional capacity, walking velocity and motor symptom severity in individuals with mild to moderate PD. According to Paker and colleagues (2015), a gait speed of 0.88m/s is required to adequately navigate in the community. Therefore, increasing and maintaining gait speed in PD is essential and was achieved by the current intervention together with improved FC that relates to independence and improved mobility. This shows that over ground gait retraining in both directions can be beneficial for PD individuals.

Backward gait retraining can be a beneficial alternative for rehabilitation purposes of parameters related to a shuffling gait pattern under ST conditions; however, other mobility aspects such as postural transitions and turning, remained unaffected by backwards gait retraining. As BW was a novel task for all participants in the BWG, they needed a period to become accustomed to the task. Therefore, while the BWG went through a familiarization period, the FWG could have used that time to their advantage in the FW exercises. Gait retraining in the forward direction can

however be beneficial for postural transitions. A possible explanation for this is that FW is more task specific. By adding a non-exercising control group, one would be able to see if BW was better than no exercise; however, BW is not superior to FW during gait retraining.

Improvements in ST and DT performances illustrates that the ability of PD individuals to learn remains relatively preserved. From this it is clear that the direction of gait retraining should reflect the direction of the transitional movements. Therefore, exercise therapist should keep in mind that BW should not replace FW.

Even though both groups improved a variety of physical variables, these objective improvements did not relate to subjective assessments of their own abilities. As balance confidence correlates to balance performance (Lohnes & Earhart 2010), it might be that the current intervention, even though effective for some mobility aspects, did not improve overall stability and balance performance.

Considering results from the current study, dopamine tends to improve velocity-dependent parameters, but not those that entail control and timing of movement, such as turning. Also, dopamine medication is not beneficial for DT performance in mild to moderate PD, which is a much more relevant daily condition (Elshehabi et al. 2016). Moreover, early indications of mobility impairments should not be overlooked and interventions for fall prevention are paramount to rehabilitation strategies. Therefore, alternative strategies that improve DT performance should be implemented.

6.7 Conclusion

Mobility, specifically gait, is a significant factor that influences a person's chance of returning to social life and daily activities. Rehabilitation is an effective treatment for restoring gait in PD. Both forward and backward over ground gait retraining for eight-weeks can be beneficial for improving functional capacity, walking velocity and motor symptom severity in individuals with mild to moderate PD.

Additionally, backward gait retraining also improved single task SL, cadence and variability in GC time; however, SL variability was increased. Forward, over ground gait retraining can be beneficial for functional mobility as measured with the i5xSTS and iTUG performance under single task conditions, as well as for turning velocity and turning angle.

Under dual task conditions, the FWG improved (decreased) interference for stride length; whereas the BWG improved (decreased) interference for variance in percentage double support

as well as deteriorated (increased) interference for percentage double support and swing time gait asymmetry.

In conclusion, backward gait retraining can be a beneficial alternative for rehabilitation purposes of some gait parameters; however, other mobility aspects, such as postural transition and turning, remained unaffected by backwards gait retraining. Therefore, exercise therapist should keep in mind that backwards walking should not replace forward walking, especially not for PD individuals with high motor scores and who present predominantly with postural instability and gait difficulty.

REFERENCES

Albani, G. et al., 2014. "Masters and servants in parkinsonian gait: A three-dimensional analysis of biomechanical changes sensitive to disease progression. *Functional Neurology*, 29(2), pp.99-105.

Abbruzzese, G. et al., 2016. Rehabilitation for Parkinson's disease: Current outlook and future challenges. *Parkinsonism and Related Disorders*, 22, pp.S60–S64. Available at: http://dx.doi.org/10.1016/j.parkreldis.2015.09.005.

Adame, M.R. et al., 2012. TUG Test Instrumentation for Parkinson's disease patients using Inertial Sensors and Dynamic Time Warping. *Biomedical Engineering / Biomedizinische Technik*, 57(SI-1 Track-E), pp.5–9. Available at: http://www.degruyter.com/view/j/bmte.2012.57.issue-s1-E/bmt-2012-4426/bmt-2012-4426.xml.

Alberts, J.L. et al., 2011. It's not about the Bike, It's About the Pedaling. *Exercise and Sport Sciences Reviews*, 39(4), p.177-186.

Allen, N.E. et al., 2010. The effects of an exercise program on fall risk factors in people with Parkinson's disease: A randomized controlled trial. *Movement Disorders*, 25(9), pp.1217–1225.

Almeida, L.R.S. et al., 2014. Recurrent falls in people with parkinson's disease without cognitive impairment: Focusing on modifiable risk factors. *Parkinson's Disease*, 432924, pp.1-8..

Almeida, Q.J. & Lebold, C.A., 2010. Freezing of gait in Parkinson's disease: A perceptual cause for a motor impairment? *Journal of Neurology, Neurosurgery & Psychiatry*, 81(5), pp.513–518. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=psyh&AN=2010-22361-011&site=ehost-live%5Cnqalmeida@wlu.ca.

Alves, G. et al., 2008. Epidemiology of Parkinson's disease. *Journal of Neurology*, 255(5), pp.18–32.

Arena, R. et al., 2007. Assessment of functional capacity in clinical and research settings: A scientific statement from the American Heart Association committee on exercise, rehabilitation, and prevention of the council on clinical cardiology and the council on cardiovascular n. *Circulation*, 116(3), pp.329–343.

Atterbury, E.M., 2016. Home-based balance training for dynamic balance in independent- living individuals with Parkinson's disease. *Doctoral dissertation, Stellenbosch University*, (March).

Azulay, J.P., Mesure, S. & Blin, O., 2006. Influence of visual cues on gait in Parkinson's disease: Contribution to attention or sensory dependence? *Journal of the Neurological Sciences*, 248(1–2), pp.192–195.

Balasubramanian, C.K., Clark, D.J. & Gouelle, A., 2015. Validity of the Gait Variability Index in older adults: Effect of aging and mobility impairments. *Gait and Posture*, 41(4), pp.941–946. Available at: http://dx.doi.org/10.1016/j.gaitpost.2015.03.349.

Baltadjieva, R. et al., 2006. Marked alterations in the gait timing and rhythmicity of patients with de novo Parkinson's disease. *European Journal of Neuroscience*, 24(6), pp.1815–1820.

Beauchet, O. et al., 2005. Stride-to-stride variability while backward counting among healthy young adults Olivier. *Journal of neuroengineering and rehabilitation*, 2(August), pp.1–8. Available at: http://www.jneuroengrehab.com/content/2/1/26.

Beck, E.N., Martens, K.A.E. & Almeida, Q.J., 2015. Freezing of gait in Parkinson's disease: An overload problem? *PLoS ONE*, 10(12). Available at: http://dx.doi.org/10.1371/journal.pone.0144986.

Bello, O. et al., 2014. Spatiotemporal parameters of gait during treadmill and overground walking in Parkinson's disease. *Journal of Parkinson's Disease*, 4(1), pp.33–36.

Bello, O., Sanchez, J.A. & Fernandez-del-olmo, M., 2008. Treadmill Walking in Parkinson ' s Disease Patients : Adaptation and Generalization Effect, 23(9), pp.1243–1249.

Bhatt, T. et al., 2013. Effect of externally cued training on dynamic stability control during the sit-to-stand task in people with Parkinson disease. *Physical therapy*, 93(4), pp.492–503. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3613339&tool=pmcentrez&rendertype=abstract.

Bloem, B.R. et al., 2004. Falls and freezing of Gait in Parkinson's disease: A review of two interconnected, episodic phenomena. *Movement Disorders*, 19(8), pp.871–884.

Bloem, B.R., Grimbergen, Y.A.M. & Cramer, M., 2001. Prospective assessment of falls in Parkinson's disease, 248, pp.950–958.

Bloem, B.R., de Vries, N.M. & Ebersbach, G., 2015. Nonpharmacological treatments for patients with Parkinson's disease. *Movement Disorders*, 30(11), pp.1504–1520.

Bovonsunthonchai, S. et al., 2014. Spatiotemporal Gait Parameters for Patients with Parkinson's Disease Compared with Normal Individuals. *Physiotherapy Research International*, 19(3), pp.158–165.

Brauer, S.G. et al., 2011. Single and dual task gait training in people with Parkinson's disease: a protocol for a randomised controlled trial. *BMC neurology*, 11, pp.90-97. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3155494&tool=pmcentrez&rendertype=abstract.

Brichetto, G. et al., 2006. Evaluation of physical therapy in parkinsonian patients with freezing of gait : a pilot study. *Clinical Rehabilitation*, 20, pp.31–35.

de Bruin, N. et al., 2010. Walking with music is a safe and viable tool for gait training in Parkinson's disease: the effect of a 13-week feasibility study on single and dual task walking. *Parkinson's disease*, p.483530.

Bryant, M.S. et al., 2011. Effects of levodopa on forward and backward gait patterns in persons with Parkinson's disease. *NeuroRehabilitation*, 29(3), pp.247–252.

Bryant, M.S. et al., 2011. Gait variability in Parkinson's disease: influence of walking speed and dopaminergic treatment. *Neurological Research*, 33(9), pp.959–964.

Cakit, B.D. et al., 2007. The effects of incremental speed-dependent treadmill training on postural instability and fear of falling in Parkinson's disease. *Clinical rehabilitation*, 21(8), pp.698–705.

Canning, C.G., 2005. The effect of directing attention during walking under dual-task conditions in Parkinson's disease. *Parkinsonism and Related Disorders*, 11(2), pp.95–99.

Canning, C.G. et al., 2006. Walking capacity in mild to moderate Parkinson's disease. *Archives of Physical Medicine and Rehabilitation*, 87(3), pp.371–375.

Canning, C.G., Ada, L. & Woodhouse, E., 2008. Multiple-task walking training in people with mild to moderate Parkinson ' s disease : a pilot study. *Clinical rehabilitation*, 22, pp.226–233.

Cereda, E. et al., 2013. Anthropometric indices of fat distribution and cardiometabolic risk in Parkinson's disease. *Nutrition, metabolism, and cardiovascular diseases : NMCD*, 23(3), pp.264–71. Available at: http://www.sciencedirect.com/science/article/pii/S0939475311000998.

Cha, H., Kim, T. & Kim, M., 2016. Therapeutic efficacy of walking backward and forward on a slope in normal adults, pp.1901–1903.

Chagas, M.H.N. et al., 2013. Validation and internal consistency of patient health questionnaire-9 for major depression in parkinson's disease. *Age and Ageing*, 42(5), pp.645–649.

Cheng, F.Y. et al., 2014. Factors influencing turning and its relationship with falls in individuals with Parkinson's disease. *PLoS ONE*, 9(4), pp.1–6.

Childs, J.D. et al., 2002. The effect of repeated bouts of backward walking on physiologic efficiency. *Journal of strength and conditioning research / National Strength & Conditioning Association*, 16(3), pp.451–455.

Chou, P. & Lee, S., 2013. Turning de fi cits in people with Parkinson ' s disease. *Tzu Chi Medical Journal*, 25(4), pp.200–202. Available at: http://dx.doi.org/10.1016/j.tcmj.2013.06.003.

Cilia, R. et al., 2014. The modern pre-levodopa era of Parkinson's disease: insights into motor complications from sub-Saharan Africa. *Brain : a journal of neurology*, 137(10), pp.2731–2742.

Cohen, R.G. et al., 2015. Lighten Up: Specific Postural Instructions Affect Axial Rigidity and Step Initiation in Patients With Parkinson's Disease. *Neurorehabilitation and Neural Repair*, 29(9), pp.878–888. Available at: http://nnr.sagepub.com/cgi/doi/10.1177/1545968315570323.

Cole, M.H. et al., 2010. Falls in Parkinson's disease: Kinematic evidence for impaired head and trunk control. *Movement Disorders*, 25(14), pp.2369–2378.

Combs-Miller, S. et al., 2014. Body Weight-Supported Treadmill Training vs. Over-Ground Walking Training for Persons With Chronic Stroke: A Randomized Controlled Trial. *Clinical Rehabilitation*, 28(9), pp.834–834. Available at: http://cre.sagepub.com/cgi/doi/10.1177/0269215514547095.

Curtze, C. et al., 2015. Levodopa Is a Double-Edged Sword for Balance and Gait in People With Parkinson's Disease. *Movement Disorders*, 30(10), pp.1361–1370.

Curtze, C. et al., 2016. Objective Gait and Balance Impairments Relate to Balance Confidence and Perceived Mobility in People With Parkinson's Disease. *Physical therapy*, 96, pp.1-26.. Available at: http://ptjournal.apta.org/content/early/2016/05/04/ptj.20150662.

Dalrymple-Alford, J.C. et al., 2010. The MoCA: Well-suited screen for cognitive impairment in Parkinson disease. *Neurology*, 75(19), pp.1717–1725.

Danion, F. et al., 2003. Stride variability in human gait: The effect of stride frequency and stride length. *Gait and Posture*, 18(1), pp.69–77.

Danoudis, M. & Iansek, R., 2014. Gait in Huntington¿s disease and the stride length-cadence relationship. *BMC neurology*, 14(1), pp.161-167. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=4190343&tool=pmcentrez&rendertype=abstract.

DePaul, V.G. et al., 2011. Varied overground walking-task practice versus body-weight-supported treadmill training in ambulatory adults within one year of stroke: a randomized controlled trial protocol. *BMC Neurology*, 11(1), pp.129. Available at: http://www.biomedcentral.com/1471-2377/11/129.

Doheny, E.P. et al., 2011. An instrumented sit-to-stand test used to examine differences between older fallers and non-fallers. *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, pp.3063–3066.

Dufek, J. et al., 2011. Backward Walking: A Possible Active Exercise for Low Back Pain Reduction and Enhanced Function in Athletes. *Journal of Exercise Physiology Online*, 14(2), pp.17–26. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=65237695&site=ehost-live.

Duncan, R.P., Leddy, A.L. & Earhart, G.M., 2011. Five Times Sit to Stand Test Performance in Parkinson Disease. *Archives of physical medicine and rehabilitation*, 92(9), pp.1431–1436.

Earhart, G.M. & Falvo, M.J., 2013. Parkinson disease and exercise. *Comprehensive Physiology*, 3(2), pp.833–848.

El-Basatiny, H.M.Y. & Abdel-Aziem, A.A., 2015. Effect of backward walking training on postural balance in children with hemiparetic cerebral palsy: a randomized controlled study. *Clinical rehabilitation*, 29(5), pp.457–67.

El-Gohary, M. et al., 2013. Continuous monitoring of turning in patients with movement disability. *Sensors (Basel, Switzerland)*, 14(1), pp.356–369.

Elbers, R.G. et al., 2013. Is gait speed a valid measure to predict community ambulation in patients with Parkinson's disease? *Journal of Rehabilitation Medicine*, 45(4), pp.370–375.

Ellis, T.D. et al., 2015. Identifying clinical measures that most accurately reflect the progression of disability in Parkinson disease. *Parkinsonism and Related Disorders*, (February).

Elshehabi, M. et al., 2016. Limited effect of dopaminergic medication on straight walking and turning in early-to-moderate parkinson's disease during single and dual tasking. *Frontiers in Aging Neuroscience*, 8(4), 1-8.

Enright, P.L., 2003. The Six-Minute Walk Test. *Respiratory Care*, 48, pp.783–785.

Espay, A.J. et al., 2012. "On" state freezing of gait in Parkinson disease: A paradoxical levodopa-induced complication. *Neurology*, 78(7), pp.454–457.

Falvo, M.J. & Earhart, G.M., 2009a. Reference equation for 6-minute walk in individuals with Parkinson disease. *The Journal of Rehabilitation Research and Development*, 46(9), pp.1121. Available at: http://www.ncbi.nlm.nih.gov/pubmed/2867249%5Cnhttp://www.rehab.research.va.gov/jour/09/46/9/pdf/falvo.pdf.

Falvo, M.J. & Earhart, G.M., 2009b. Six-Minute Walk Distance in Persons With Parkinson Disease: A Hierarchical Regression Model. *Archives of Physical Medicine and Rehabilitation*, 90(6), pp.1004–1008. Available at: http://dx.doi.org/10.1016/j.apmr.2008.12.018.

Fernandes-Silva, M.M. et al., 2017. Inflammatory biomarkers and effect of exercise on functional capacity in patients with heart failure – insights from a ... Page Proof Instructions and Queries. *European Journal of Preventative Cardiology*, 0, p.1-10.

Fernandes, A et al., 2015. Influence of dual-task on sit-to-stand-to-sit postural control in Parkinson's disease. *Medical Engineering and Physics*, 37(11), pp.1070–1075.

Fernandes, Â. et al., 2015. Effects of dual-task training on balance and executive functions in Parkinson's disease: A pilot study. *Somatosensory & motor research*, 220, pp.1–6. Available at: http://www.ncbi.nlm.nih.gov/pubmed/25874637.

Fisher, B.E. et al., 2008. The Effect of Exercise Training in Improving Motor Performance and Corticomotor Excitability in People With Early Parkinson's Disease. *Archives of Physical Medicine and Rehabilitation*, 89(7), pp.1221–1229.

Fok, P. et al., 2011. The effects of verbal instructions on gait in people with Parkinson's disease: a systematic review of randomized and non-randomized trials. *Clinical rehabilitation*, 25, pp.396–407.

Frazzitta, G. et al., 2009. Rehabilitation treatment of gait in patients with Parkinson's disease with freezing: A comparison between two physical therapy protocols using visual and auditory cues with or without treadmill training. *Movement Disorders*, 24(8), pp.1139–1143.

Frenkel-Toledo, S. et al., 2005. Treadmill walking as an external pacemaker to improve gait rhythm and stability in Parkinson's disease. *Movement Disorders*, 20(9), pp.1109–1114.

Fuller, R.L. et al., 2013. Dual task performance in Parkinson's disease: A sensitive predictor of impairment and disability. *Parkinsonism and Related Disorders*, 19(3), pp.325–328.

Ganesan, M. et al., 2015. Partial Body Weight-Supported Treadmill Training in Patients with Parkinson Disease: Impact on Gait and Clinical Manifestation. *Archives of Physical Medicine and Rehabilitation*, 96(9), pp.1557–1565. Available at: http://dx.doi.org/10.1016/j.apmr.2015.05.007.

Garber, C.E. & Friedman, J.H., 2003. Effects of fatigue on physical activity and function in patients with Parkinson's disease. *Neurology*, 60(7), pp.1119–1124. Available at: http://graphics.tx.ovid.com/ovftpdfs/FPDDNCIBBFBAON00/fs024/ovft/live/gv013/00006114/00006114-200304080-00015.pdf.

Goetz, C.G. et al., 2007. Movement disorder society-sponsored revision of the unified Parkinson's disease rating scale (MDS-UPDRS): Process, format, and clinimetric testing plan. *Movement Disorders*, 22(1), pp.41–47.

Goetz, C.G. et al., 2008. Movement Disorder Society-Sponsored Revision of the Unified Parkinson's Disease Rating Scale (MDS-UPDRS): Scale presentation and clinimetric testing results. *Movement Disorders*, 23(15), pp.2129–2170.

Goodwin, V.A. et al., 2008. The effectiveness of exercise interventions for people with Parkinson's disease: A systematic review and meta-analysis. *Movement Disorders*, 23(5), pp.631–640.

Gordon, P.C. et al., 2016a. Instrumented quantitative study of movement and gait in Parkinson's disease clinical subtypes, pp.27–28.

Grasso, R., Bianchi, L. & Lacquaniti, F., 1998. Motor patterns for human gait: backward versus forward locomotion. *Journal of neurophysiology*, 80(4), pp.1868–1885.

Gregory, T. & Welman, K., 2015. Somatosensory training for postural control in independent-living individuals with Parkinson's disease. *Doctoral dissertation, Stellenbosch University*, (December).

Hackney, M.E. & Earhart, G.M., 2010. Effects of dance on gait and balance in Parkinson's disease: a comparison of partnered and nonpartnered dance movement. *Neurorehabilitation and neural repair*, 24(4), pp.384–92. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2900796&tool=pmcentrez&rendertype=abstract.

Hackney, M.E. & Earhart, G.M., 2009. Effects of dance on movement control in Parkinson's disease: A comparison of Argentine tango and American ballroom. *Journal of Rehabilitation Medicine*, 41(6), pp.475–481.

Hackney, M.E. & Earhart, G.M., 2011. The Effects of a Secondary Task on Forward and Backward Walking in Parkinson Disease. *Neurorehabilitation and neural repair*, pp.1–14.

Hak, L. et al., 2013. Steps to take to enhance gait stability: The effect of stride frequency, stride length, and walking speed on local dynamic stability and margins of stability. *PLoS ONE*, 8(12), pp.1-8..

Hass, C.J. et al., 2014. Defining the clinically meaningful change in gait speed in Parkinson's disease. *Journal of Neurologic Physical Therapy*, 38(4), pp.233-238. Available at: http://www.ncbi.nlm.nih.gov/pubmed/25198866.

Hausdorff, J.M., 2007. Gait dynamics, fractals and falls: Finding meaning in the stride-to-stride fluctuations of human walking. *Human Movement Science*, 26(4), pp.555–589.

Hausdorff, J.M., 2005. Gait variability : methods , modeling and meaning Example of Increased Stride Time Variability in Elderly Fallers Quantification of Stride-to-Stride Fluctuations, 9(19), pp.1–9.

Hausdorff, J.M. et al., 2003. Impaired regulation of stride variability in Parkinson's disease subjects with freezing of gait. *Experimental brain research. Experimentelle Hirnforschung. Expérimentation cérébrale*, 149(2), pp.187–94. Available at: http://www.ncbi.nlm.nih.gov/pubmed/12610686.

Hausdorff, J.M. et al., 2007. Rhythmic auditory stimulation modulates gait variability in Parkinson's disease. *European Journal of Neuroscience*, 26(8), pp.2369–2375.

Hausdorff, J.M. et al., 2005. Walking is more like catching than tapping: Gait in the elderly as a complex cognitive task. *Experimental Brain Research*, 164(4), pp.541–548.

Hedayatpour, N. & Falla, D., 2015. Physiological and Neural Adaptations to Eccentric Exercise: Mechanisms and Considerations for Training. *BioMed Research International*, 193741, pp.1-8..

Herman, T. et al., 2014a. Gait and balance in Parkinson's disease subtypes: objective measures and classification considerations. *Journal of Neurology*, 261(12), pp.2401–2410.

Herman, T. et al., 2014b. Identifying axial and cognitive correlates in patients with Parkinson's disease motor subtype using the instrumented Timed Up and Go. *Experimental Brain Research*, 232(2), pp.713–721.

Herman, T. et al., 2007. Six Weeks of Intensive Treadmill Training Improves Gait and Quality of Life in Patients With Parkinson's Disease: A Pilot Study. *Archives of Physical Medicine and Rehabilitation*, 88(9), pp.1154–1158.

Herman, T. et al., 2009. The Dynamic Gait Index in healthy older adults: The role of stair climbing, fear of falling and gender. *Gait and Posture*, 29(2), pp.237–241.

Herman, T., Giladi, N. & Hausdorff, J.M., 2009. Treadmill training for the treatment of gait disturbances in people with Parkinson's disease: A mini-review. *Journal of Neural Transmission*, 116(3), pp.307–318.

Hill, K.D. et al., 2015. Individualized home-based exercise programs for older people to reduce falls and improve physical performance: A systematic review and meta-analysis. *Maturitas*, 82(1), pp.72–84. Available at: http://dx.doi.org/10.1016/j.maturitas.2015.04.005.

Hoehn, M.M. & Yahr, M.D., 1967. Parkinsonism: onset, progression, and mortality, 17(5), pp.427-442.

Holden, M.K., Gill, K.M. & Magliozzi, M.R., 1986. Gait assessment for neurologically impaired patients. Standards for outcome assessment. *Physical therapy*, 66(10), pp.1530–9. Available at: http://www.ncbi.nlm.nih.gov/pubmed/3763704.

Hollman, J.H. et al., 2016. A comparison of variability in spatiotemporal gait parameters between treadmill and overground walking conditions. *Gait and Posture*, 43, pp.204–209. Available at: http://dx.doi.org/10.1016/j.gaitpost.2015.09.024.

Hollman, J.H., McDade, E.M. & Petersen, R.C., 2011. Normative spatiotemporal gait parameters in older adults. *Gait and Posture*, 34(1), pp.111–118. Available at: http://dx.doi.org/10.1016/j.gaitpost.2011.03.024.

Hong, M. & Earhart, G.M., 2010. Effects of medication on turning deficits in individuals with Parkinson's disease. *Journal of neurologic physical therapy*, 34(1), pp.11–6. Available at: http://www.ncbi.nlm.nih.gov/pubmed/20212362%5Cnhttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC2886796.

Hoogkamer, W., Meyns, P. & Duysens, J., 2014. Steps forward in understanding backward gait: From basic circuits to rehabilitation. *Exercise and Sport Sciences Reviews*, 42(1), pp.23–29.

Hooper, T.L. et al., 2004. The effects of graded forward and backward walking on heart rate and oxygen consumption. *The Journal of orthopaedic and sports physical therapy*, 34(2), pp.65–71.

Hoops, S. et al., 2009. Validity of the MoCA and MMSE in the detection of MCI and dementia in Parkinson disease. *Neurology*, 73(21), pp.1738–1745.

Horak, F.B. et al., 2016. Balance and Gait Represent Independent Domains of Mobility in Parkinson Disease. *Physical therapy*, 96(9), pp.1364–71. Available at: http://www.ncbi.nlm.nih.gov/pubmed/27034314%5Cnhttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC5009185.

Horak, F.B. & Mancini, M., 2013. Objective biomarkers of balance and gait for Parkinson's disease using body-worn sensors. *Movement Disorders*, 28(11), pp.1544–1551.

Horváth, K. et al., 2015. Minimal clinically important difference on the Motor Examination part of MDS-UPDRS. *Parkinsonism and Related Disorders*, 21(12), pp.1421–1426.

Houles, M. et al., 2010. Gait speed at usual pace as a predictor of adverse outcomes in community-dwelling older people [French] La vitesse de marche comme critere de fragilite chez la personne agee vivant au domicile. *Cahiers de l'Annee Gerontologique*, 2(1), pp.13–23. Available at: http://link.springer.com/10.1007/s12603-009-0246-z%5CnAvailable from SpringerLink in http://link.worldcat.org/?rft.institution_id=129749&spage=13&pkgName=nesli&issn=1760-5342,1760-5350&linkclass=to_article&jKey=12612&issue=1&provider=springerlink&date=2010&.

Hulbert, S. et al., 2015. A narrative review of turning deficits in people with Parkinson's disease. *Disability and Rehabilitation*, 37(14–15), pp.1382–1389.

Hulbert, S. et al., 2014. Towards a better understanding of turning deficits in people with Parkinson's. *Ispgr*, pp.10–11.

Jacobs, J. V. et al., 2009. The supplementary motor area contributes to the timing of the anticipatory postural adjustment during step initiation in participants with and without Parkinson's disease. *Neuroscience*, 164(2), pp.877–885.

James, E.G. et al., 2016. Gait coordination impairment is associated with mobility in older adults. *Experimental Gerontology*, 80, pp.12–16.

Jankovic, J., 2008. Parkinson's disease: clinical features and diagnosis. *Journal of Neurology, Neurosurgery & Psychiatry*, 79(4), pp.368–376. Available at: http://jnnp.bmj.com/cgi/doi/10.1136/jnnp.2007.131045.

Jenkinson, C. et al., 1997. The Parkinson's disease questionnaire (PDQ-39): Development and validation of a Parkinson's disease summary index score. *Age and Ageing*, 26(5), pp.353–357.

Johnson, A.R. et al., 2016. Motor Subtype as a Predictor of Future Working Memory Performance in Idiopathic Parkinson's Disease. *Plos One*, 11(3), e0152534. Available at: http://dx.plos.org/10.1371/journal.pone.0152534.

Jones, J., Rikli, R., 2002. Fitness of older adults. *The Journal on Active Aging*, pp.24–30.

Kim, K., Lee, S. & Lee, K., 2014. Effects of Progressive Body Weight Support Treadmill Forward and Backward Walking Training on Stroke Patients' Affected Side Lower Extremity's Walking Ability. *J Phys Ther Sci*, 26, pp.1923-1927.

Kelly, V.E., Eusterbrock, A.J. & Shumway-Cook, A., 2012. A review of dual-task walking deficits in people with Parkinson's disease: Motor and cognitive contributions, mechanisms, and clinical implications. *Parkinson's Disease*, 918719, pp.1-14.

Keus, S. et al., 2014. European Physiotherapy Guideline for Parkinson ' s Disease Developed with twenty European professional associations. *KNGF/ParkinsonNet, the Netherlands*, 1(1), p.32.

Keus, S.H.J. et al., 2007. Evidence-based analysis of physical therapy in Parkinson's disease with recommendations for practice and research. *Movement Disorders*, 22(4), pp.451–460.

Khalil, H. et al., 2012. Adherence to use of a home-based exercise DVD in people with Huntington disease: participants' perspectives. *Physical Therapy*, 92(1), pp.69–82. Available at: http://www.ncbi.nlm.nih.gov/pubmed/21960468%5Cnhttp://search.ebscohost.com/login.aspx?direct=true&db=cmedm&AN=21960468&site=ehost-live.

Khobkhun, F. et al., 2014. Effect of physical therapy training on gait initiation in patients with moderate parkinson's disease. *Chiang Mai University Journal of Natural Sciences*, 13(1), pp.43–50.

Kim, S.-G. et al., 2013. Backward walking treadmill therapy can improve walking ability in children with spastic cerebral palsy: a pilot study. *International Journal of Rehabilitation Research*, 36(3), pp.246–252.

King, L. et al., 2015. Do cognitive measures and brain circuitry predict outcomes of exercise in Parkinson Disease: a randomized clinical trial. *BMC Neurology*, 15(1), p.218. Available at: http://www.biomedcentral.com/1471-2377/15/218.

King, L.A. et al., 2013. Exploring outcome measures for exercise intervention in people with Parkinson's disease. *Parkinson's Disease*, 572134, pp.1-9.

King, L.A et al., 2012. Do clinical scales of balance reflect turning abnormalities in people with Parkinson's disease? *Journal of neurologic physical therapy*, 36(1), pp.25–31. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3290336&tool=pmcentrez&rendertype=abstract.

Koch, S. et al., 2009. Body Locomotion as Regulatory Process Stepping Backward Enhances Cognitive Control. , 20(5), pp.549–551.

König, N. et al., 2016. Can Gait Signatures Provide Quantitative Measures for Aiding Clinical Decision-Making? A Systematic Meta-Analysis of Gait Variability Behavior in Patients with Parkinson's Disease. *Frontiers in human neuroscience*, 10, pp.319. Available at: http://www.ncbi.nlm.nih.gov/pubmed/27445759%5Cnhttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC4927578.

König, N. et al., 2014. Identification of functional parameters for the classification of older female fallers and prediction of "first-time" fallers. *Journal of the Royal Society, Interface / the Royal Society*, 11(97), pp.20140353. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-84903639590&partnerID=tZOtx3y1.

Kroenke, K., Spitzer, R.L. & Williams, J.B.W., 2001. The PHQ-9: Validity of a brief depression severity measure. *Journal of General Internal Medicine*, 16(9), pp.606–613.

LaRoche, D.P., Cook, S.B. & Mackala, K., 2012. Strength Asymmetry Increases Gait Asymmetry and Variability in Older Women. , 44(11), pp.2172–2181.

Laufer, Y., 2005. Effect of age on characteristics of forward and backward gait at preferred and accelerated walking speed. *The journals of gerontology. Series A, Biological sciences and medical sciences*, 60(5), pp.627–632.

Lee, M. et al., 2013. Kinematic and kinetic analysis during forward and backward walking. *Gait & posture*, 38(4), pp.674–8. Available at: http://dx.doi.org/10.1016/j.gaitpost.2013.02.014.

Lewis, G.N., Byblow, W.D. & Walt, S.E., 2000. Stride length regulation in Parkinson's disease: the use of extrinsic, visual cues. *Brain: a journal of neurology*, 123(1), pp.2077–2090.

Lim, I. et al., 2005. Effects of external rhythmical cueing on gait in patients with Parkinson's disease: a systematic review. *Clinical Rhabilitation*, 19, pp.695–713.

Lim, L. et al., 2005. Measuring gait and gait-related activities in Parkinson's patients own home environment: A reliability, responsiveness and feasibility study. *Parkinsonism and Related Disorders*, 11(1), pp.19–24.

Lima, L.O., Scianni, A. & Rodrigues-de-Paula, F., 2013. Progressive resistance exercise improves strength and physical performance in people with mild to moderate Parkinson's disease: a systematic review. *J Physiother*, 59(1), pp.7–13.

Liu, J. & Lockhart, T.E., 2009. Trunk Angular Kinematics during Slip-Induced Falls and Activities of Daily Living – Towards Developing a Fall Detector. *Human Factors and Ergonomics Society Annual Meeting Proceedings*, 53(14), pp.892–896.

Lobuono, D.L. et al., 2016. Cognitive status and cardio-metabolic risk of patients with acquired brain injury and Parkinson's disease. *Disability and Health Journal*, 9(1), pp.134–139. Available at: http://www.journals.elsevier.com/disability-and-health-journal/%5Cnhttp://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=emed13&NEWS=N&AN=2015183405.

Lohnes, C.A. & Earhart, G.M., 2010. External validation of abbreviated versions of the activities-specific balance confidence scale in Parkinson's disease. *Movement Disorders*, 25(4), pp.485–489.

Lord, S. et al., 2011. Gait variability in Parkinson's disease: An indicator of non-dopaminergic contributors to gait dysfunction? *Journal of Neurology*, 258(4), pp.566–572.

Muller-Oehring, E.M. et al., 2014. Task-rest modulation of basal ganglia connectivity in mild to moderate Parkinson's disease. *Brain Imaging and Behavior*, 9(3), pp.619–638.

Mak, M.K.Y., Pang, M.Y.C. & Mok, V., 2012. Gait difficulty, postural instability, and muscle weakness are associated with fear of falling in people with Parkinson's disease. *Parkinson's Disease*, 901721, pp.1–6.

Mancini, M.et al., 2015. Continuous monitoring of turning in Parkinson's disease: Rehabilitation potential. *NeuroRehabilitation*, 37(1), pp.3–10.

Mancini, M.et al., 2015. Effect of augmenting cholinergic function on gait and balance. *BMC neurology*, 15(1), p.264. Available at: http://www.ncbi.nlm.nih.gov/pubmed/26697847.

Mancini, M. et al., 2012. Quantifying freezing of gait in Parkinson's disease during the instrumented timed up and go test. *IEEE Engineering in Medicine and Biology Society.* (August 2016), pp.1198–201. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=4140195&tool=pmcentrez&rendertype=abstract.

Mancini, M. & Horak, F.B., 2016. Potential of APDM Mobility Lab for the monitoring of the progression of Parkinson's disease. *Expert Review of Medical Devices*, 13(5), pp.455-462. Available at: http://www.tandfonline.com/doi/full/10.1586/17434440.2016.1153421.

Martin, K.L. et al., 2013. Cognitive function, gait, and gait variability in older people: A population-based study. *Journals of Gerontology - Series A Biological Sciences and Medical Sciences*, 68(6), pp.726–732.

Martinez-Martin, P. et al., 2015. Impact of Pharmacotherapy on Quality of Life in Patients with Parkinson's Disease. *CNS Drugs*, 29(5), pp.397–413.

Martinez-Martin, P. et al., 2011. The impact of non-motor symptoms on health-related quality of life of patients with Parkinson's disease. *Movement Disorders*, 26(3), pp.399–406.

Masumoto, K. et al., 2007. A comparison of muscle activity and heart rate response during backward and forward walking on an underwater treadmill. *Gait and Posture*, 25(2), pp.222–228.

Mazilu, S. et al., 2015. A Wearable Assistant for Gait Training for Parkinson&Rsquo;s Disease with Freezing of Gait in Out-of-the-Lab Environments. *ACM Trans. Interact. Intell. Syst.*, 5(1), pp.5-31. Available at: http://doi.acm.org/10.1145/2701431.

Mazilu, S. et al., 2016. The role of wrist-mounted inertial sensors in detecting gait freeze episodes in Parkinson's disease. *Pervasive and Mobile Computing*, pp.1-16.

Mcauley, E. & Tamrnen, V. V, 1989. The Effects of Subjective and Objective Competitive Outcomes on Intrinsic Motivation, pp.84–93.

McIsaac, T.L., Lamberg, E.M. & Muratori, L.M., 2015. Building a framework for a dual task taxonomy. *BioMed Research International*, 591475, pp.1-10.

Mehrholz, J. et al., 2016. Treadmill training for patients with Parkinson's disease. An abridged version of a Cochrane Review. *European journal of physical and rehabilitation medicine*, pp.1-71.

Mellone, S. et al., 2016. The quality of turning in Parkinson ' s disease : a compensatory strategy to prevent postural instability ? *Journal of NeuroEngineering and Rehabilitation*, 13(39), pp.1–9. Available at: http://dx.doi.org/10.1186/s12984-016-0147-4.

Melo Santiago, L.M. et al., 2015. Immediate effects of adding mental practice to physical practice on the gait of individuals with Parkinson's disease: Randomized clinical trial. *NeuroRehabilitation*, 37(2), pp.263–271. Available at: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L606875267%5Cnhttp://dx.doi.org/10.3233/NRE-151259%5Cnhttp://sfx.library.uu.nl/utrecht?sid=EMBASE&issn=18786448&id=doi:10.3233/NRE-151259&atitle=Immediate+effects+of+adding+mental+practi.

Meyns, P. et al., 2014. Interlimb coordination during forward walking is largely preserved in backward walking in children with cerebral palsy. *Clinical Neurophysiology*, 125(3), pp.552–561. Available at: http://dx.doi.org/10.1016/j.clinph.2013.08.022.

Michaelsen, S.M. et al., 2014. Effect of backward walking treadmill training on walking capacity after stroke: A randomized clinical trial. *International Journal of Stroke*, 9(4), pp.529–532.

Millor, N. et al., 2014. Kinematic parameters to evaluate functional performance of sit-to-stand and stand-to-sit transitions using motion sensor devices: A systematic review. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 22(5), pp.926–936.

Miura, K. et al., 2015. Neuropsychological Characteristics and Their Association with Higher-Level Functional Capacity in Parkinson's Disease. *Dementia and geriatric cognitive disorders extra*, 5(2), pp.271–84. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=4521071&tool=pmcentrez&rendertype=abstract.

Miyai, I. et al., 2000. Treadmill training with body weight support: Its effect on Parkinson's disease. *Archives of Physical Medicine and Rehabilitation*, 81(7), pp.849–852.

Monteiro-Junior, R.S. et al., 2015. We need to move more: Neurobiological hypotheses of physical exercise as a treatment for Parkinson's disease. *Medical Hypotheses*, 85(5), pp.537–541. Available at: http://dx.doi.org/10.1016/j.mehy.2015.07.011.

Moore, O., Peretz, C. & Giladi, N., 2007. Freezing of gait affects quality of life of peoples with Parkinson's disease beyond its relationships with mobility and gait. *Movement Disorders*, 22(15), pp.2192–2195.

Moore, S.T., MacDougall, H.G. & Ondo, W.G., 2008. Ambulatory monitoring of freezing of gait in Parkinson's disease. *Journal of Neuroscience Methods*, 167(2), pp.340–348.

Morris, M.E. et al., 1996. Stride length regulation in Parkinson's disease Normalization strategies and underlying mechanisms. *Brain*, 119, pp.551–568.

Moustafa, A.A. et al., 2016. Motor symptoms in Parkinson's disease: A unified framework. *Neuroscience and Biobehavioral Reviews*, 68, pp.727–740. Available at: http://dx.doi.org/10.1016/j.neubiorev.2016.07.010.

Nagal, A. & Singla, R.K., 2016. Parkinson â€™s Disease : Diagnosis , Therapeutics & Management Parkinson â€™s Disease : Diagnosis , Therapeutics & Management. *WebmedCentral PHARMACEUTICAL SCIENCES*, 3(8), p.WMC003670. Available at: http://www.webmedcentral.com/article_view/3670 Subject.

Nanhoe-Mahabier, W. et al., 2011. Walking patterns in Parkinson's disease with and without freezing of gait. *Neuroscience*, 182, pp.217–224. Available at: http://dx.doi.org/10.1016/j.neuroscience.2011.02.061.

Nieuwboer, A. et al., 2009. Motor learning in Parkinson's disease: limitations and potential for rehabilitation. *Parkinsonism and Related Disorders*, 15(3), pp.53–58.

Nieuwboer, a et al., 2007. Cueing training in the home improves gait-related mobility in Parkinson's disease: the RESCUE trial. *Journal of neurology, neurosurgery, and psychiatry*, 78(2), pp.134–140.

Nilsson, M.H. et al., 2012. Walking ability is a major contributor to fear of falling in people with Parkinson's disease: Implications for rehabilitation. *Parkinson's Disease*, 713236, pp.1-7.

O'Shea, S., Morris, M.E. & Iansek, R., 2002. Research Report in People With Parkinson Disease : Effects of Motor Versus Cognitive. *Journal of the American Physical Therapy Association*, 82(9), pp.888–897.

Oberg, T., Karsznia, A. & Oberg, K., 1993. Basic gait parameters: reference data for normal subjects, 10-79 years of age. *Journal of rehabilitation research and development*, 30(2), pp.210–23. Available at: http://www.rehab.research.va.gov/jour/93/30/2/pdf/oberg.pdf.

Orcioli-Silva, D. et al., 2014. Effects of a multimodal exercise program on the functional capacity of Parkinson's disease patients considering disease severity and gender. *Motriz. Revista de Educacao Fisica*, 20(1), pp.100–106.

Paker, N. et al., 2015. Gait speed and related factors in Parkinson's disease. *Journal of physical therapy science*, 27(12), pp.3675–9. Available at: http://www.ncbi.nlm.nih.gov/pubmed/26834330%5Cnhttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC4713769.

Pearce, V. & Wilson, I., 2007. Parkinson's disease in Africa. *Age and Ageing*, 36(2), pp.116–117.

Peppe, A. et al., 2007. Does gait analysis quantify motor rehabilitation efficacy in Parkinson's disease patients? *Gait and Posture*, 26(3), pp.452–462.

Peters, C. et al., 2012. A randomized controlled trial of an enhanced interdisciplinary community based group program for people with Parkinson's disease: study rationale and protocol. *Neurology international*, 4(e3), pp.9-14.Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3349958&tool=pmcentrez&rendertype=abstract.

Peterson, D.S. et al., 2014. Brain activity during complex imagined gait tasks in Parkinson disease. *Clinical Neurophysiology*, 125(5), pp.995–1005. Available at: http://dx.doi.org/10.1016/j.clinph.2013.10.008.

Peterson, D.S. et al., 2012. Evidence for a relationship between bilateral coordination during complex gait tasks and freezing of gait in Parkinson's disease. *Parkinsonism and Related Disorders*, 18(9), pp.1022–1026. Available at: http://dx.doi.org/10.1016/j.parkreldis.2012.05.019.

Peterson, D.S. & Horak, F.B., 2016. Neural Control of Walking in People with Parkinsonism. *Physiology*, 31(2), pp.95–107. Available at: http://physiologyonline.physiology.org/lookup/doi/10.1152/physiol.00034.2015.

Peto, V., Jenkinson, C. & Fitzpatrick, R.A.Y., 2001. Determining minimally important differences for the PDQ-39 Parkinson's disease questionnaire. *Age and Ageing*, 30(4), pp.299–302.

Petzinger, G.M. et al., 2013. Exercise-enhanced neuroplasticity targeting motor and cognitive circuitry in Parkinson's disease. *The Lancet Neurology*, 12(7), pp.716–726. Available at: http://dx.doi.org/10.1016/S1474-4422(13)70123-6.

Pieruccini-Faria, F. et al., 2014. Interactions between cognitive and sensory load while planning and controlling complex gait adaptations in Parkinson's disease. *BMC neurology*, 14, pp.1-24. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=4302136&tool=pmcentrez&rendertype=abstract.

Plotnik, M. et al., 2005. Is freezing of gait in Parkinson's disease related to asymmetric motor function? *Annals of Neurology*, 57(5), pp.656–663.

Plotnik, M. et al., 2011. Postural instability and fall risk in Parkinson's disease: Impaired dual tasking, pacing, and bilateral coordination of gait during the "on" medication state. *Experimental Brain Research*, 210(3), pp.529–538.

Plotnik, M., Giladi, N. & Hausdorff, J.M., 2007. A new measure for quantifying the bilateral coordination of human gait: Effects of aging and Parkinson's disease. *Experimental Brain Research*, 181(4), pp.561–570.

Plotnik, M., Giladi, N. & Hausdorff, J.M., 2008. Bilateral coordination of walking and freezing of gait in Parkinson's disease. *European Journal of Neuroscience*, 27(8), pp.1999–2006.

Plummer, P. & Eskes, G., 2015. Measuring treatment effects on dual-task performance: a framework for research and clinical practice. *Frontiers in human neuroscience*, 9, pp.1-7. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=4412054&tool=pmcentrez&rendertype=abstract.

Pohl, M. et al., 2003. Immediate Effects of Speed-Dependent Treadmill Training on Gait Parameters in Early Parkinson's Disease. *Archives of Physical Medicine and Rehabilitation*, 84(12), pp.1760–1766.

Protas, E.J. et al., 2005. Gait and step training to reduce falls in Parkinson's disease. *NeuroRehabilitation*, 20(3), pp.183–190.

Ridgel, A.L., Vitek, J.L. & Alberts, J.L., 2009. Forced, not voluntary, exercise improves motor function in Parkinson's disease patients. *Neurorehabilitation and neural repair*, 23(6), pp.600–8.

Rochester, L. et al., 2010. Evidence for motor learning in Parkinson's disease: Acquisition, automaticity and retention of cued gait performance after training with external rhythmical cues. *Brain Research*, 1319, pp.103–111.

Rochester, L. et al., 2005. The effect of external rhythmic cues (auditory and visual) on walking during a functional task in homes of people with Parkinson's disease. *Archives of Physical Medicine and Rehabilitation*, 86(5), pp.999–1006.

Rodriguez-Blazquez, C. et al., 2013. The MDS-UPDRS Part II (motor experiences of daily living) resulted useful for assessment of disability in Parkinson's disease. *Parkinsonism and Related Disorders*, 19(10), pp.889–893.

Roiz, R.D.M. et al., 2010. Gait analysis comparing Parkinson's disease with healthy elderly subjects. *Arquivos de neuro-psiquiatria*, 68(1), pp.81–86.

Rosenfeldt, A.B. et al., 2015. The cyclical lower extremity exercise for Parkinson's trial (CYCLE): methodology for a randomized controlled trial. *BMC neurology*, 15(1), p.63. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-84928569463&partnerID=tZOtx3y1.

Sabari, J.S. et al., 2015. Activity engagement and health quality of life in people with Parkinson's disease. *Disability and rehabilitation*, 37(16), pp.1411–5. Available at: http://www.ncbi.nlm.nih.gov/pubmed/25332087.

Salarian, A. et al., 2004. Gait assessment in Parkinson's disease: Toward an ambulatory system for long-term monitoring. *IEEE Transactions on Biomedical Engineering*, 51(8), pp.1434–1443.

Salarian, A. et al., 2010. ITUG, a sensitive and reliable measure of mobility. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 18(3), pp.303–310.

Schaafsma, J.D. et al., 2003. Gait dynamics in Parkinson's disease: Relationship to Parkinsonian features, falls and response to levodopa. *Journal of the Neurological Sciences*, 212(1), pp.47–53.

Schenkman, M. et al., 1997. Reliability of impairment and physical performance measures for persons with Parkinson's disease. *Physical therapy*, 77(1), pp.19–27.

Schenkman, M. et al., 2012. Research Report Exercise for People in Early- or Mid- Stage Parkinson Disease : A 16-Month Randomized Controlled Trial. *Journal of the American Physical Therapy Association*, 92(11), pp.1395–1411.

Schneider, J.S., Sendek, S. & Yang, C., 2015. Relationship between motor symptoms, cognition, and demographic characteristics in treated mild/moderate Parkinson's disease. *PLoS ONE*, 10(4), pp.1–11. Available at: http://dx.doi.org/10.1371/journal.pone.0123231.

Shen, X. & Mak, M.K.Y., 2014. Balance and Gait Training With Augmented Feedback Improves Balance Confidence in People With Parkinson's Disease: A Randomized Controlled Trial. *Neurorehabilitation and neural repair*, 28(6), pp.524–535. Available at: http://www.ncbi.nlm.nih.gov/pubmed/24407915.

Shulman, L.M. et al., 2008. The evolution of disability in Parkinson disease. *Movement Disorders*, 23(6), pp.790–796.

Simoes, M.A., 2011. Feasibility of Wearable Sensors to Determine Gait Parameters. *Doctural dissertation, University of Florida (July)*.

Smania, N. et al., 2010. Effect of balance training on postural instability in patients with idiopathic Parkinson's disease. *Neurorehabilitation and neural repair*, 24(9), pp.826–834.

Smulders, K. et al., 2016. Parkinsonism and Related Disorders Pharmacological treatment in Parkinson's disease: Effects on gait. *Parkinsonism and Related Disorders*, pp.1-11. Available at: http://dx.doi.org/10.1016/j.parkreldis.2016.07.006.

Snijders, A.H. et al., 2011. Gait-related cerebral alterations in patients with Parkinson's disease with freezing of gait. *Brain*, 134(1), pp.59–72.

Snijders, A.H., Nonnekes, J. & Bloem, B.R., 2010. Recent advances in the assessment and treatment of falls in Parkinson's disease. *F1000 medicine reports*, 2, pp.1-4. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2981191&tool=pmcentrez&rendertype=abstract.

Sollinger, A.B. et al., 2010. Mild cognitive impairment in Parkinson's disease: Subtypes and motor characteristics. *Parkinsonism and Related Disorders*, 16(3), pp.177–180.

Son, H. & Kim, E., 2015. Kinematic analysis of arm and trunk movements in the gait of Parkinson's disease patients based on external signals. *Journal of physical therapy science*, 27(12), pp.3783–6. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=4713791&tool=pmcentrez&rendertype=abstract.

Song, J. et al., 2012. Altered dynamic postural control during step turning in persons with early-stage Parkinson's disease. *Parkinson's Disease*, 386962, pp.1-8..

Springer, S. et al., 2006. Dual-tasking effects on gait variability: The role of aging, falls, and executive function. *Movement Disorders*, 21(7), pp.950–957.

Stack, E. & Ashburn, a, 2008. Dysfunctional turning in Parkinson's disease. *Disability and rehabilitation*, 30(16), pp.1222–1229.

Stebbins, G.T. et al., 2013. How to identify tremor dominant and postural instability/gait difficulty groups with the movement disorder society unified Parkinson's disease rating scale: Comparison with the unified Parkinson's disease rating scale. *Movement Disorders*, 28(5), pp.668–670.

Steffen, T. & Seney, M., 2008. Test-retest reliability and minimal detectable change on balance and ambulation tests, the 36-item short-form health survey, and the unified Parkinson disease rating scale in people with parkinsonism. *Physical therapy*, 88(6), pp.733–746.

Stegemöller, E.L. et al., 2014. Timed up and go, cognitive, and quality-of-life correlates in Parkinson's Disease. *Archives of Physical Medicine and Rehabilitation*, 95(4), pp.649–655.

Stergiou, N., Harbourne, R.T. & Cavanaugh, J.T., 2006. Optimal Movement Variability: A New Theoretical Perspective for Neurologic Physical Therapy. *Journal of Neurologic Physical Therapy*, 30(3), pp.120–129. Available at: http://journals.lww.com/jnpt/Abstract/2006/09000/Optimal_Movement_Variability__A_New_Theoretical.6.aspx.

Strouwen, C. et al., 2015. Dual tasking in Parkinson's disease: should we train hazardous behavior? *Expert review of neurotherapeutics*, 15(9), pp.1031–1039.

Studenski, S. et al., 2003. Physical performance measures in the clinical setting. *Journal of the American Geriatrics Society*, 51(3), pp.314–22.

Sugiura, Y. et al., 2016. Association between Functional Capacity Decline and Nutritional Status Based on the Nutrition Screening Initiative Checklist: A 2-Year Cohort Study of Japanese Community-Dwelling Elderly. *Plos One*, 11(11), pp.e0166037. Available at: http://dx.plos.org/10.1371/journal.pone.0166037.

Šumec, R. et al., 2015. Psychological Benefits of Nonpharmacological Methods Aimed for Improving Balance in Parkinson's Disease: A Systematic Review. *Behavioural neurology*, 620674, pp.1-18. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=4508472&tool=pmcentrez&rendertype=abstract.

Taipei, J.Y. et al., 2005. Gait outcomes after additional backward walking training in patients with stroke : a randomized controlled trial, pp.264–273.

Tamás, G. et al., 2014. Quality of life and costs in Parkinson's disease: A cross sectional study in Hungary. *PLoS ONE*, 9(9), pp.1–7.

Tang, P.F. et al., 2015. Motor dual-task Timed Up & Go test better identifies prefrailty individuals than single-task Timed Up & Go test. *Geriatrics and Gerontology International*, 15(2), pp.204–210.

Terblanche, E. et al., 2005. The effect of backward locomotion training on the body composition and cardiorespiratory fitness of young women. *International Journal of Sports Medicine*, 26(3), pp.214–219.

Thalheimer, W. & Cook, S., 2002. How to calculate effect sizes from published research: A simplified methodology. *Work-Learning Research*, (August), pp.1–9. Available at: http://www.bwgriffin.com/gsu/courses/edur9131/content/Effect_Sizes_pdf5.pdf%5Cnwww.work-learning.com.

Thevathasan, W. et al., 2012. A spatiotemporal analysis of gait freezing and the impact of pedunculopontine nucleus stimulation. *Brain*, 135(5), pp.1446–1454.

Todorov, E. & Jordan, M.I., 2002. Supp Optimal feedback control as a theory of motor coordination. *Nat. Neurosci.*, 5(11), pp.1226–1235. Available at: http://www.ncbi.nlm.nih.gov/pubmed/12404008.

Toole, T. et al., 2005. The effects of loading and unloading treadmill walking on balance, gait, fall risk, and daily function in Parkinsonism. *NeuroRehabilitation*, 20(4), pp.307–322.

Toosizadeh, N. et al., 2015. Motor performance assessment in Parkinson's disease: Association between objective in-clinic, objective in-home, and subjective/semi-objective measures. *PLoS ONE*, 10(4), pp.1–15. Available at: http://dx.doi.org/10.1371/journal.pone.0124763.

Tramontano, M. et al., 2016. Blindfolded Balance Training in Patients with Parkinson's Disease: A Sensory-Motor Strategy to Improve the Gait. *Parkinson's Disease*, 2016.

Tseng, I.J., Yuan, R.Y. & Jeng, C., 2015. Treadmill Training Improves Forward and Backward Gait in Early Parkinson Disease. *American Journal of Physical Medicine & Rehabilitation*, pp.811-819. Available at: http://content.wkhealth.com/linkback/openurl?sid=WKPTLP:landingpage&an=00002060-900000000-99135.

Ullmann, G. & Williams, H.G., 2011. The relationships among gait and mobility under single and dual task conditions in community-dwelling older adults. *Aging clinical and experimental research*, 23(5), pp.400–405. Available at: http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=medl&NEWS=N&AN=20859069.

Vandenbossche, J. et al., 2012. Freezing of gait in Parkinson's disease: disturbances in automaticity and control. *Frontiers in human neuroscience*, 6, pp.1-11. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3541536&tool=pmcentrez&rendertype=abstract.

Vandenbossche, J. et al., 2011. Freezing of gait in Parkinson disease is associated with impaired conflict resolution. *Neurorehabilitation and neural repair*, 25(8), pp.765–773.

Vervoort, G. et al., 2016. Progression of postural control and gait deficits in Parkinson's disease and freezing of gait: A longitudinal study. *Parkinsonism and Related Disorders*, 28, pp.73–79. Available at: http://dx.doi.org/10.1016/j.parkreldis.2016.04.029.

Wang, Y.L. et al., 2015. Body Mass Index and Risk of Parkinson's Disease: A Dose-Response Meta-Analysis of Prospective Studies. *PloS one*, 10(6), pp.e0131778.

Weiss, A. et al., 2014. New evidence for gait abnormalities among Parkinson's disease patients who suffer from freezing of gait: insights using a body-fixed sensor worn for 3 days. *Journal of Neural Transmission*, (July), pp.403–410.

Whitney, S.L. et al., 2005. Clinical measurement of sit-to-stand performance in people with balance disorders: validity of data for the Five-Times-Sit-to-Stand Test. *Physical therapy*, 85(10), pp.1034–1045.

Wirdefeldt, K. et al., 2011. Epidemiology and etiology of Parkinson's disease: a review of the evidence. *European journal of epidemiology*, 26(1), pp.S1–S58.

Woo, T., Tseng, H. & Liu, B., Evaluating the Difference of Physiological Load between Forward and Backward Exercise, pp.464–472.

Wu, T., Hallett, M. & Chan, P., 2015. Motor automaticity in Parkinson's disease. *Neurobiology of Disease*, 82, pp.226–234.

Wuehr, M. et al., 2013. Differential effects of absent visual feedback control on gait variability during different locomotion speeds. *Experimental Brain Research*, 224(2), pp.287–294.

Yang, Y.-R. et al., 2007. Dual-task exercise improves walking ability in chronic stroke: a randomized controlled trial. *Archives of Physical Medicine & Rehabilitation*, 88(10), pp.1236–1240. Available at: http://www.ncbi.nlm.nih.gov/pubmed/17908563.

Yang, Y.-R. et al., 2005. Gait outcomes after additional backward walking training in patients with stroke: a randomized controlled trial. *Clinical rehabilitation*, 19(3), pp.264–273.

Yang, Y.R. et al., 2008. Relationships between gait and dynamic balance in early Parkinson's disease. *Gait and Posture*, 27(4), pp.611–615.

Yogev-Seligmann, G. et al., 2012. A training program to improve gait while dual tasking in patients with Parkinson's disease: A pilot study. *Archives of Physical Medicine and Rehabilitation*, 93(1), pp.176–181.

Yogev-Seligmann, G., Hausdorff, J.M. & Giladi, N., 2008. The role of executive function and attention in gait. *Movement Disorders*, 23(3), pp.329–342.

Yogev, G. et al., 2005. Dual tasking, gait rhythmicity, and Parkinson's disease: Which aspects of gait are attention demanding? *European Journal of Neuroscience*, 22(5), pp.1248–1256.

Yogev, G. et al., 2007. Gait asymmetry in patients with Parkinson's disease and elderly fallers: When does the bilateral coordination of gait require attention? *Experimental Brain Research*, 177(3), pp.336–346.

Zhang, X. et al., 2014. Investigating the role of backward walking therapy in alleviating plantar pressure of patients with diabetic peripheral neuropathy. *Archives of Physical Medicine and Rehabilitation*, 95(5), pp.832–839. Available at: http://dx.doi.org/10.1016/j.apmr.2014.01.003.

APPENDIX A Summary of eight-week gait retraining program

Table A1 *Warm-up and Cool-down sequences that were alternated throughout the training program. Exercises progressed from sitting to standing to chair or wall support*

Warm-up	Cool-down
Sequence 1	
• Side step and tap with side arm lifts • Ankle pumps • Ankle rotations • Knee extension & flexion • Hip marching • Trunk rotations • Shoulder rolls • Neck flexion and extension	• Reaching backward/forward • Stretch: quadriceps, calves, trunk (lateral bending) • Whole body muscle contraction and relaxation
Sequence 2	
• Standing ball kicks • Heel raises • Ankle ABC's • Knee extension & flexion • Hip lift & Abduction • Lateral trunk flexion • Arm circles • Neck rotations	• Weight shifts • Reaching sideways • Stretch: hamstrings, trunk (rotations), neck • Muscle contractions and relaxation (Muscle groups separately)
Sequence 3	
• Standing ball kicks in circle • Toe taps • Ankle clocks • Isometric knee extension & knee and hip flexion • Standing hip circles • Trunk rotations • Arm swings • Head movements	• Coordinated movements with breathing • Stretch: calves, hamstrings, neck (pocket stretch) • Breathing with chin-to-chest and chin-to-shoulder • Deep breathing with upper body to facilitate an open chest

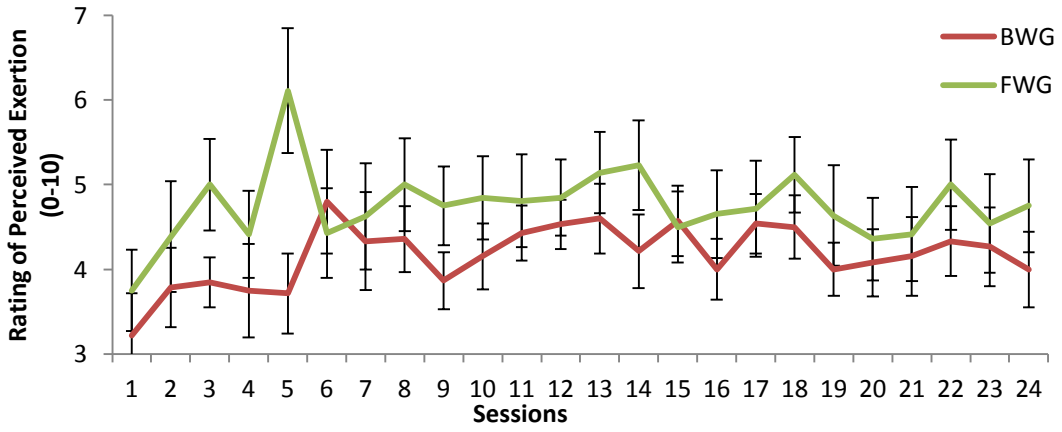
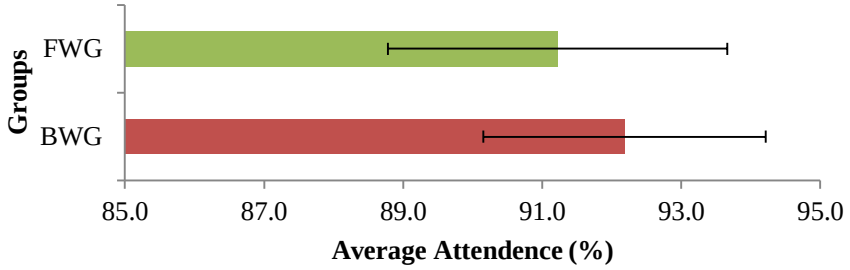
Table A2 *Outline of eight-week gait retraining program with objectives and examples of exercises. The forward and backward walking groups performed exercises in opposite directions*

Week 1	
To become familiarized with proper posture and gait task: Foot strike and Push off	• Postural cueing (seated and standing): pelvis, shoulders, neck & head, trunk • Weight shifting: seated & standing (alternate base of support) • Reaching: seated & standing (alternate base of support, i.e. normal, narrow or tandem stance)
Week 2	
To become familiarized with gait task: Focusing on step length	• Step strategy (normal and narrow stance) • Walking technique at initial contact • Weight shifts with stepping • Marching • Arm swing (broomsticks)
Week 3	
Focus on overall over ground walking technique: Coordination & Gait initiation	• Coordination: upper and lower limbs • Diagonal and sideways walking with foot taps and arm coordination • Gait initiation: rocking before stepping • Dual task walking: categorical lists
Week 4	
To increase velocity, cadence and distance walking	• On-demand speed changes • Decision-making speed changes • Striding out with increased speed while controlling momentum • Dual task walking: verbal fluency
Week 5	
Focus on directional change abilities	• Dynamic walking tasks: high knee, butt-kick • Pattern walking • Turning: 90°, 180°, 360° • Dual task walking: discriminating and decision making

Table A2 Continued…Outline of eight-week gait retraining program with objectives and examples of exercises. The forward and backward walking groups performed exercises in opposite directions

Week 6	
Concentrating on obstacle negotiation & ability to manoeuvre through tight spaces	• Sideways walking (mirror partner) • Stepping over objects on floor: ropes, cones , combination • Walking on narrow walkway • Stepping over objects on narrow walkway • Zigzag through cones • Approaching chairs • Dual task walking: motor task, working memory
Week 7	
Focus on locomotion as it relates to daily activities	• Dynamic walking tasks • Sideways walking: along a rope with stepping over object • Navigating through narrow spaces in-between chairs • Walk & perform task: fold cloth, count coins, tie a knot, putting pegs on a hanger, etc. • Sit-to-stand & walk around chair • Dual task walking: motor task, cognitive and functional strategies
Week 8	
Performing circuit training	• Perform sequences of previously learned tasks

Table A3 Principles and additional details of the eight-week gait retraining program

Parameter	Information
Setting	Sessions were held indoors on a hard surface next to chairs and walls to which participants could hold on to. Participants were instructed to wear the same, standard footwear as during testing sessions.
Frequency	3x / week (24 sessions)
Duration	Total: 45-60 minutes per session ▪ 20-30 minutes over ground gait retraining ▪ 5-10 minutes of other activities (warm-up, reaching, relaxation, etc.) ▪ 5-10 minutes stretching
Type of activities	• Walking while focusing on different gait-related aspects • Utilizing different types of cues • Negotiating different obstacles • Adding motor tasks • Adding cognitive tasks
Groups	Forward walking group (FWG): performed the different gait tasks in the forward direction Backward walking group (BWG): performed the different gait tasks in the backward direction
Intensity	
Attendence	

APPENDIX B

PERSONAL & HEALTH INFORMATION
Personal Information
Name:
Surname:
Age:
ID number:
Gender:
Home Language:
Occupation (If retired, please indicate and state previous occupation): _____
Medical Aid Information Medical aid name: _____ Main member: _____ ID number of main member: _____ Medical aid number: _____
Contact Details
Cell phone number (c):
Home telephone number (h):
E-mail address:
Preferred contact method: □ (c) □ (h) □ Email
Physical Address: _____ _____ _____ _____
Emergency Contact Details
Name and surname:
Contact number: (c) _____ (h) _____
Relationship:

roneg25@gmail.com

Orthopaedic History

Do you have a recent history of, or currently have, any of the following?

□ Joint injury/pain □ Muscle injury/pain

If yes, please tick the appropriate box(es):

□ Neck □ Upper back □ Lower back □ Hip

□ Thigh □ Knee □ Lower leg □ Ankle

□ Foot (drop) □ Shoulder □ Elbow □ Wrist / Hand

□ Other (Please specify):

_____

_____

_____

Medical History

Do you have a history of any of the following? Please tick the appropriate boxes:

□ Heart attack □ Coronary thrombosis □ Narrowing arteries

□ High cholesterol □ High Blood pressure □ Leaking valve

□ Stroke □ Angina / Chest pains □ Palpitations

□ Rheumatoid fever □ Known heart murmur

□ Other heart condition or disease:_____

□ Oedema / swelling of ankles □ Low blood pressure □ Seizures

□ Breathing problems / difficulties □ Lung disease □ Fainting / dizziness

□ Cancer □ Diabetes □ Intermittent claudication

□ Colonoscopy □ Gastroscopy □ Colour blind

□ Recent operation (Please specify): _____

□ Unusual fatigue / shortness of breath

□ Pain / discomfort in chest, neck, jaw or arms

Disease Related History

When were you diagnosed with Parkinson's disease?

Level of Parkinson's disease (if known): □ I □ II □ III □ IV □ V

□ Not known

Most affected side: □ Left □ Right □ Both

Most affected body part: □ Arms □ Legs □ Both □ Other: _____

Do you use a walking aid (i.e. walker, walking stick, etc.)? □ Yes □ No

roneg25@gmail.com

If yes, please specify: _____

Are you on regular medication? □ Yes □ No

If yes, please complete the following:

Name	Dosage	Duration of usage	Purpose

Any adverse effects of medication:

_____

_____

_____

_____

_____

Activity Level

What household chores do you do?

Type	Times per week	Duration

What leisure time activities do you do?

Type	Times per week	Duration

roneg25@gmail.com

How often do you participate in physical activity or exercise?

Type	Times per week	Duration

Caregiver Information

Name and surname:

Contact number:

Relationship:

Time spent daily without caregiver:

Would your caregiver like to attend the training sessions as well? □ Yes □ No

Doctor's Information

Name and surname:

Contact number:

Speciality: □ Neurologist □ Internist □ General Practitioner

□ Other (Please specify): _____

Has your doctor given you approval to participate in this study? □ Yes □ No

Would you mind if we contact him/her? □ Yes □ No

Has your doctor previously indicated any other conditions (not mentioned in this form) that we should know of? □ Yes □ No

If yes, please specify:

_____

_____

Availability

Are you going away anytime between now and the end of July 2016? □ Yes □ No

If yes, please state the dates:

_____

_____

_____

_____

THANK YOU

roneg25@gmail.com

APPENDIX C List of anti-Parkinson medication and affected side of both groups

Forward walking group			Backward walking group		
	Medication	**Affected body part**		**Medication**	**Affected body part**
1	Teva Carbi-Levo Symmetrel Parkilyne	Both legs	**1**	Carbilev Carbi-Levo Oxpola	Right arm & leg
2	Teva Carbi-Levo Sinemet Cr Symmetrel Pexola Pexola ER	Right leg	**2**	Teva Carbi-Levo Pexola	Both arms
3	None	Left arm & leg	**3**	Carbilev	Left leg
4	Carbilev Sinemet	Left arm & leg	**4**	Carbilev	Left arm & leg
5	Carbilev	Both legs	**5**	Carbilevo Pexola	Right leg
6	Carbilev	Left leg	**6**	Madopar	Both legs
7	Teva Carbi-Levo Pexola	Right arm	**7**	Carbilev	Both arms and legs
8	Carbi Levo	Both legs	**8**	Teva Carbi-levo	Both legs
9	Carbilev Pexola Symadine	Right arm	**9**	Carbilev Sinemet	Both arms and legs
10	Carbilev	Right arm	**10**	Carbilev	Left arm and leg
11	Sinamed Accord Ropinirole	Right leg	**11**	Carbilev	Both legs
12	Carbilev	Left arm	**12**	Teva Levodopa	Both arms and legs
13	Carbilev Sinemet	Left arm & leg	**13**	Madopar	Both arms and legs
14	Carbilev	Right leg	**14**	Carbilev	Right arm
			15	Carbi-Levo Madopor	Left arm and leg

APPENDIX D

PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM

TITLE OF THE RESEARCH PROJECT:

Comparison between Forward and Backward Gait Retraining for Mobility in individuals with mild to moderate Parkinson's disease.

REFERENCE NUMBER: S16/01/004S

PRINCIPAL INVESTIGATOR: Roné Grobbelaar

ADDRESS: Department of Sport Science
University of Stellenbosch
Matieland
7602

CONTACT NUMBER: 083 357 5424

You are being invited to take part in a research study conducted by Roné Grobbelaar (BScHons. Biokinetics) and Dr Karen Welman (PhD Sport Science), from the Sport Science Department at Stellenbosch University. The results of the study will contribute to research paper(s) as well as an MSc thesis. You were selected as a possible participant in this study because you have mild to moderate Parkinson's disease.

Please take some time to read the information presented here, which will explain the details of this project. Please ask the study staff or doctor any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

This study has been approved by the **Health Research Ethics Committee at Stellenbosch University** and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research. The records of this study can be accessed by the Research Ethical Committee as well as the Departmental Ethics Screening Committee of Stellenbosch University.

What is this research study all about?

The research aim of this study will be to explore the effect of backward gait training, for eight weeks, on mobility in individuals with mild to moderate Parkinson's disease.

Outline

During this study, individuals with Parkinson's disease will follow a physical training program for eight weeks. Participants will be tested before the onset of the training program as well as thereafter. During these eight weeks, it will be required of participants to attend three training sessions per week. Each session will last 45-60 minutes. The study will consist of an experimental and a control group who will participate in separate training sessions. The training program for both groups will focus on gait retraining. All participants should take their anti-Parkinson's medication as usual and will be tested in the on-state of medication usage. Furthermore, participants may not change their medication usage or exercise habits during the study period.

Screening

Once participants are recruited, they will be tested to meet the participation criteria. After this, data will be coded to ensure confidentiality. Only the researchers will have access to these data files.

Group assignment

Once all participants have been recruited and tested, they will be randomly divided into either the experimental or control group. To ensure that participants are divided randomly, an offsite investigator who will not be involved in any stage of this study will perform the randomization.

Assessments

Participants will have to complete a variety of physical tasks and questionnaires (sent via email or a hardcopy). An outline of the assessments follows:

For screening purposes (on-site), the following will be used:

1. Personal and Health Information
2. Montreal Cognitive Assessment (MoCA) for global cognitive function.*
3. Patient Health Questionnaire (PHQ-9) for depressive state.

The on-site testing procedures will include:

1. Movement Disorder Society - Unified Parkinson's Disease Rating Scale (MDS-UPDRS) Part III for motor impairments and disability.*
2. A variety of functional tasks will be performed to assess mobility.*

*These tasks will be accompanied by video and/or voice recordings for referencing purposes.

The self-reported tests will include:

1. Parkinson's Disease Questionnaire – 39 (PDQ-39) for disease related history and the effect the disease has on quality of life.
2. MDS-UPDRS Part II for disease related motor experiences of daily living.
3. Freezing of Gait Questionnaire (FOG-Q) to assess freezing status.
4. Activity-specific Balance Confidence scale (ABC scale) for balance confidence.

Intervention

Participants will have three training sessions of 45-60 minutes per week, for eight weeks. Training sessions will be held indoors on a hard surface. The training program is focused on improving mobility and will be adjusted weekly to ensure progression.

Why have you been invited to participate?

You were selected as a possible participant in this study because we need individuals diagnosed with Parkinson's disease** for this study. Moreover, you

- may have impaired balance, but are able to move about without supervision or physical assistance from another individual. Assistive devices such as a walker or walking stick will be allowed. This is important as participants will not be fully supervised one-to-one throughout the whole exercise session.
- have stable medication usage with no disturbing drug-related fluctuations.
- have not followed a backward gait retraining program before.
- have not experienced a major injury which needed medical attention, within the last three months before the onset of the intervention.
- have not been diagnosed with dementia or who have a history or evidence of cognitive deficit.
- do not have diseases or impairments other than Parkinson's disease that would affect your movement or balance. These include neurological, cardiovascular or musculoskeletal problems; peripheral neuropathy, vestibular impairments etc.

** All interested individuals' neurologist will be contacted, with their permission, to clarify their diagnosis.

What will your responsibilities be?

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you don't want to answer and still remain in the study.

The researcher may withdraw you from this research if there are circumstances which require that. If a participant's medication usage changes drastically and the effect thereof influences his/her performance in the study, the participant's participation will be terminated. It will be your responsibility to inform the researcher of such changes.

If a participant experiences a major fall which requires medical attention, he or she will be withdrawn from the study. It will be your responsibility to inform the researcher of such circumstances.

As this is a research study, attending the training sessions is very important. Participants will be required to attend three training sessions per week. If an appointment cannot be kept, participants are asked to schedule another appointment with the researcher.

Will you benefit from taking part in this research?

This study aims to improve Parkinson's disease related impairments in mobility which affects participant's daily life. Participants will benefit from supervised exercise sessions by a qualified biokineticist free of charge. It can be expected that participants from both the control and experimental group will show improvements in these variables. Improvements in balance will help participants to complete high quality activities of daily living, with more confidence and success and with less fear of falling. The training intervention may also improve in cardiovascular fitness, posture and kinesthetic awareness (a sensory skill that your body uses to know where it is in space).

Are there any risks involved in your taking part in this research?

None of the measurements and tests will be invasive or place participants at risk other than what may normally occur during daily activities. To promote confidence in the participants, their partner or caretaker will be welcome to also become involved in the training sessions. All training sessions will be held under the supervision of health professionals which will consist of a qualified instructor (the main researcher) and assistants who will provide supervision where needed.

The main researcher is a qualified biokineticist. A biokineticist is a clinical exercise specialist that is concerned with health promotion, the maintenance of physical abilities and final phase rehabilitation, by means of scientifically based physical activity programme prescription. The researcher is trained in Basic Life Support and First Aid. Participation will also occur in small groups to ease supervision of and guidance for participants.

Participants should be aware of the slight possibility that they may feel some muscle soreness and fatigue 24 to 48 hours after testing and training. These risks will be minimized by performing warm-up exercises at the beginning of training sessions. Participants will be encouraged to take breaks as needed throughout testing as well as training sessions in order to prevent excessive fatigue. Training program progressions will also be designed to gradually increase intensity, which will promote improvements and decrease the possibility of muscle soreness and excessive fatigue after training sessions. If muscle soreness occurs, appropriate stretching exercises to relieve this soreness will be demonstrated.

Participants should be aware that multi-directional gait tasks will be performed during training sessions. As gait tasks may carry a risk of falling, specific safety considerations will be set in place to decrease this possibility. Sessions will be held in a low-risk environment. It will be ensured that there is no clutter on the floor or objects that participants are unaware of. Supervisors will be present in close proximity to frequently remind participants of training-related objects. Participants will perform exercises next to chairs or walls to which they can hold on to.

If you do not agree to take part, what alternatives do you have?

Participants who will not take part in the current study will be informed of other possible research studies. Also, you may be interested in a Parkinson's disease exercise group that is held at the Department of Sport Science at Stellenbosch University. If you are interested in this option, contact Elizma Atterbury (072 952 2567). Furthermore, if you are interested in exercising at a biokinetics practice, consider the following contact details:

Stellenbosch Biokinetics Centre: 021 808 4735
Danel van Pletzen Biokineticist (Paarl): 021 870 1420

Who will have access to your medical records?

Any information that is obtained in this study and that can identify you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of a data coding procedure. Therefore, participants cannot be identified directly. These codes will be used to refer to participants in the study. Only the researchers will have access to these data files. Hard as well as electronic copies of all documentation will be safeguarded at the Department of Sport Science at Stellenbosch University. Only the researcher and the researcher's supervisor will have access to these files.

Participants will have the right to review the voice and video recordings taken of them during the functional performance tasks. These recordings will be used for referencing purposes, data analyses and to support conclusions. Only the researcher and the researcher's two supervisors will have access to these recordings. The recordings will be safely stored electronically on a portable hard drive at the Department of Sport Science at Stellenbosch University. Video recordings will be kept for three years after the completion of this study and will then be erased by the supervisors.

As the researcher plans to publish results from this study, mean values of data obtained through testing procedures will be included and discussed in the publications. However, no personal information of the participants will be published. Raw data will be coded and summarized in such a manner that participant identification remains entirely confidential.

What will happen in the unlikely event of some form of injury occurring as a direct result of your taking part in this research study?

In the case of a research related event, participants can contact the principal investigator, R Grobbelaar (083 357 5424 / roneg25@gmail.com) or her study supervisor (021 808 4733 / welman@sun.ac.za) who will contact the relevant emergency or medical team. Also, insurance cover has been set in place.

All participants' emergency contact details and medical aid information will be kept on hand to be readily accessible throughout all contact session. The researcher, as well as supervisor, will have emergency numbers readily available on their mobile phones to offer the necessary medical attention in the unlikely case of an injury.

Will you be paid to take part in this study and are there any costs involved?

No, you will not be paid to take part in the study. The only costs involved in the study are travel related. On testing days, refreshments will be provided.

It will not be expected of participants to pay for any of the study procedures. Participants will benefit from supervised exercise sessions by a qualified biokineticist free of charge. Also, participating individuals have the opportunity to exercise three times a week for eight weeks with appropriate program progressions. Normally, individuals will be charged R200 to R300 per session with a biokineticist. After the intervention, a feedback session on the mean results of the group will

be held and each participant will receive his/her individual feedback compared to the mean results of the group.

Is there anything else that you should know or do?

- You should inform your family practitioner or usual doctor that you are taking part in a research study.
- You should also inform your medical insurance company that you are participating in a research study.
- You can contact Dr Karen Welman (Study supervisor) at (tel) 021 808 4733 if you have any further queries or encounter any problems.
- You can contact the Health Research Ethics Committee (HREC) at 021-938 9207 if you have any concerns or complaints that have not been adequately addressed by your study coordinator.
- If any new relevant information arises during the course of the study which will need revision of this information and consent form (ICF), HREC will first be contacted to incorporate this information before participants will be informed. Hereafter, participants will be asked to sign the adjusted ICF and participation will still be voluntary.
- You will receive a copy of this information and consent form for your own records.

Declaration by participant

By signing below, I ……..…….. agree to take part in a research study entitled *Comparison between Forward and Backward Gait Retraining for Mobility in individuals with mild to moderate Parkinson's disease*.

I declare that:

- I have read or had read to me this information and consent form and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- I may be asked to leave the study before it has finished, if the study doctor or researcher feels it is in my best interests, or if I do not follow the study plan, as agreed to.

Signed at.....…….....……. on ……..…….. 2016.

…… ……

Signature of participant **Signature of witness**

Declaration by investigator

I, Roné Grobbelaar declare that:

- I explained the information in this document to the aforementioned participant.
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did/did not use an interpreter.

Signed at (*place*) .....…..…….. on ……..…….. 2016.

…… ……

Signature of investigator **Signature of witness**

Declaration by interpreter

I, ……..…… declare that:

- I assisted the investigator, Roné Grobbelaar, to explain the information in this document to the aforementioned participant using the language medium of Afrikaans/Xhosa.
- We encouraged him/her to ask questions and took adequate time to answer them.
- I conveyed a factually correct version of what was related to me.
- I am satisfied that the participant fully understands the content of this informed consent document and has had all his/her question satisfactorily answered.

Signed at .....…..…….. on ……..……2016.

…… ……

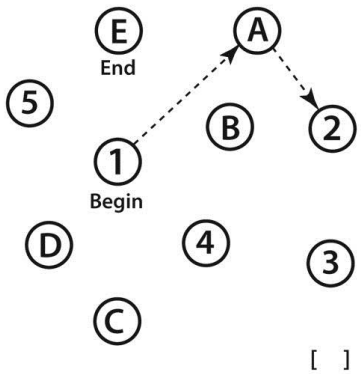
Signature of interpreter **Signature of witness**

APPENDIX E1

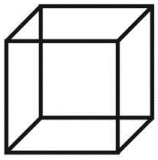
MONTREAL COGNITIVE ASSESSMENT (MOCA)
Version 7.1 Original Version

NAME :
Education : Date of birth :
Sex : DATE :

VISUOSPATIAL / EXECUTIVE — POINTS



Copy cube



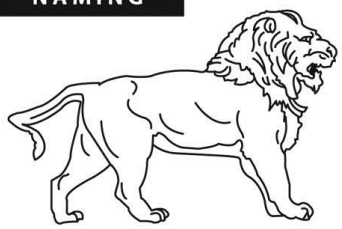
[ ] [ ]

Draw CLOCK (Ten past eleven)
(3 points)

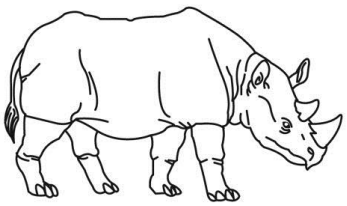
[ ] Contour [ ] Numbers [ ] Hands

__/5

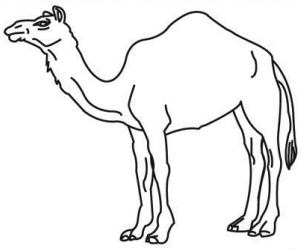
NAMING



[ ]



[ ]



[ ]

__/3

MEMORY Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful. Do a recall after 5 minutes.

	FACE	VELVET	CHURCH	DAISY	RED
1st trial					
2nd trial					

No points

ATTENTION Read list of digits (1 digit/ sec.).

Subject has to repeat them in the forward order [ ] 2 1 8 5 4
Subject has to repeat them in the backward order [ ] 7 4 2

__/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors

[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B

__/1

Serial 7 subtraction starting at 100 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65

4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt**

__/3

LANGUAGE Repeat : I only know that John is the one to help today. [ ]
The cat always hid under the couch when dogs were in the room. [ ]

__/2

Fluency / Name maximum number of words in one minute that begin with the letter F [ ] _____ (N ≥ 11 words)

__/1

ABSTRACTION Similarity between e.g. banana - orange = fruit [ ] train – bicycle [ ] watch - ruler

__/2

DELAYED RECALL

	Has to recall words **WITH NO CUE**	FACE [ ]	VELVET [ ]	CHURCH [ ]	DAISY [ ]	RED [ ]	Points for UNCUED recall only
Optional	Category cue						
	Multiple choice cue						

__/5

ORIENTATION [ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City

__/6

 www.mocatest.org Normal ≥ 26 / 30

TOTAL __/30

Add 1 point if ≤ 12 yr edu

Administered by: _____

APPENDIX E2

Afrikaanse Weergawe

MONTREAL COGNITIVE ASSESSMENT (MOCA)

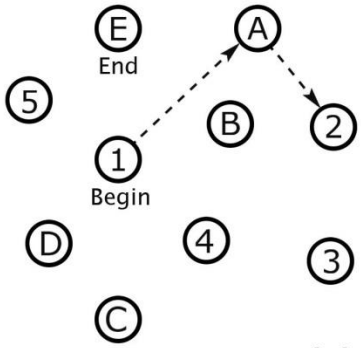
Weergawe 7.1 **www.mocatest.org**

NAAM:

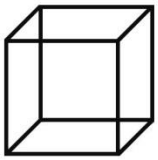
Geslag: DATUM:

Geb: Opleidingsvlak:

VISUORUIMTELIK / UITVOEREND — PUNTE



Teken die kubus oor



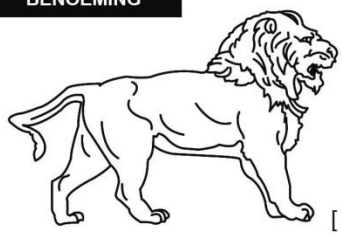
[ ] [ ]

Teken die gesig van 'n horlosie wat tien oor elf aanwys. (3 punte)

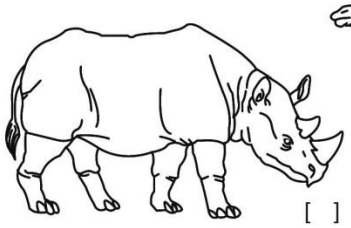
[ ] Omlyning [ ] Getalle [ ] Wysers

__/5

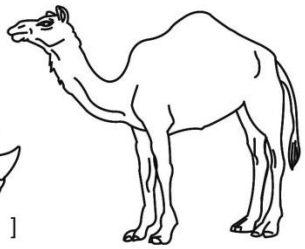
BENOEMING



[ ]



[ ]



[ ]

__/3

GEHEUE — Lees die lys van woorde. Die proefpersoon moet hulle herhaal. Doen dit 2 keer, selfs al was die eerste poging 'n sukses. Toets herroeping daarvan na 5 minute. (sien onder)

	GESIG	FLUWEEL	KERK	LELIE	ROOI
1ste poging					
2de poging					

Geen punte

AANDAG — Lees die lys van syfers (1 syfer/sek)

Proefpersoon moet syfers vorentoe herhaal. [ ] 2 1 8 5 4

Proefpersoon moet syfers agteruit sê. [ ] 7 4 2

__/2

Lees die lys van letters. Met elke letter A moet die proefpersoon met die hand tik. Geen punte ≥ 2 foute.

[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B

__/1

Begin seriële 7 aftrekkings by 100 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65

4 of 5 aftrekkings reg: **3 pte**; 2 of 3 reg: **2 pte**; 1 reg: **1 pt**; 0 reg: **0 pte**

__/3

TAAL

[ ] Herhaal: 'Ek weet net dat Johan die een is wat vandag moet help.'

[ ] 'Die kat het altyd onder die bank weggekruip, wanneer honde in die kamer was.'

__/2

Woordvlotheid: Sê soveel woorde as moontlik in 1 minuut wat begin met die letter 'L'. [ ] _____ (N ≥ 11 woorde)

__/1

ABSTRAKTE DENKE — Ooreenkoms tussen bv. piesang en lemoen = vrugte. [ ] trein - fiets [ ] horlosie - lineaal

__/2

UITGESTELDE HERROEPING

	Moet woorde herroep SONDER 'N WENK	GESIG [ ]	FLUWEEL [ ]	KERK [ ]	LELIE [ ]	ROOI [ ]	Punte slegs vir herroeping SONDER 'n wenk
Opsioneel	Kategorie wenk						
	Veelkeuse wenk						

__/5

ORIËNTASIE [ ] Datum [ ] Maand [ ] Jaar [ ] Dag [ ] Plek [ ] Stad

__/6

Afrikaanse vertaling: P M Joubert en C W Van Staden

Normaal ≥ 26/30

TOTAAL __/30

Voeg 1 punt by as ≤ 12 jr opleiding

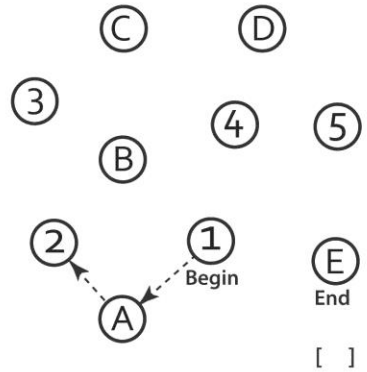
Afgeneem deur: _____

APPENDIX E3

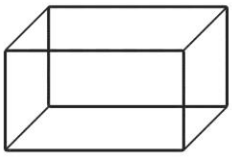
MONTREAL COGNITIVE ASSESSMENT (MOCA®)
Version 7.2 Alternative Version

NAME :
Education : Date of birth :
Sex : DATE :

VISUOSPATIAL / EXECUTIVE — POINTS



Copy rectangle



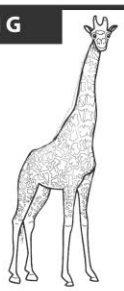
[ ] [ ]

Draw CLOCK (Five past four)
(3 points)

[ ] Contour [ ] Numbers [ ] Hands

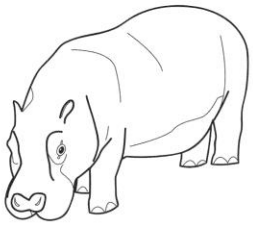
__/5

NAMING



[ ]

[ ]



[ ]

__/3

MEMORY Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful. Do a recall after 5 minutes.

	TRUCK	BANANA	VIOLIN	DESK	GREEN
1st trial					
2nd trial					

No points

ATTENTION Read list of digits (1 digit/ sec.).
Subject has to repeat them in the forward order [ ] 3 2 9 6 5
Subject has to repeat them in the backward order [ ] 8 5 2

__/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors
[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B

__/1

Serial 7 subtraction starting at 90 [ ] 83 [ ] 76 [ ] 69 [ ] 62 [ ] 55
4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt**

__/3

LANGUAGE Repeat : A bird can fly into closed windows when it's dark and windy. [ ]
The caring grandmother sent groceries over a week ago. [ ]

__/2

Fluency / Name maximum number of words in one minute that begin with the letter S [ ] _____ (N ≥ 11 words)

__/1

ABSTRACTION Similarity between e.g. carrot - potato = vegetable. [ ] diamond - ruby [ ] cannon - rifle

__/2

DELAYED RECALL

	Has to recall words **WITH NO CUE**	TRUCK [ ]	BANANA [ ]	VIOLIN [ ]	DESK [ ]	GREEN [ ]	Points for UNCUED recall only
Optional	Category cue						
	Multiple choice cue						

__/5

ORIENTATION [ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City

__/6

Adapted by : Z. Nasreddine MD, N. Phillips PhD, H. Chertkow MD
© Z.Nasreddine MD www.mocatest.org
Administered by: _____

Normal ≥ 26 / 30

TOTAL __/30
Add 1 point if ≤ 12 yr edu

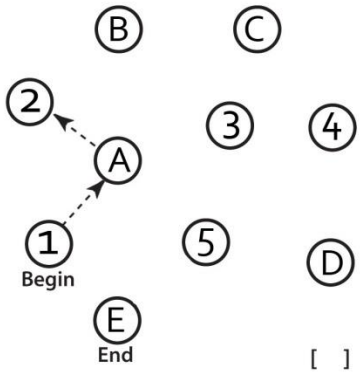
*Afrikaans translations were used for Afrikaans participants

APPENDIX E4

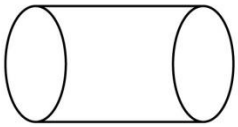
MONTREAL COGNITIVE ASSESSMENT (MOCA)
Version 7.3 Alternative Version

NAME :
Education : Date of birth :
Sex : DATE :

VISUOSPATIAL / EXECUTIVE — POINTS



Copy cylinder



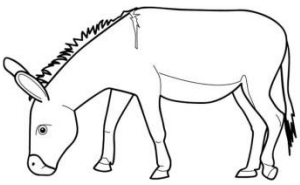
[ ] [ ]

Draw CLOCK (Ten past nine)
(3 points)

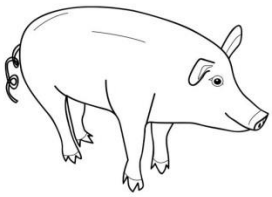
[ ] Contour [ ] Numbers [ ] Hands

__/5

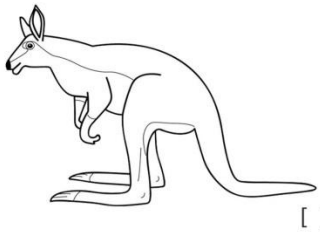
NAMING



[ ]



[ ]



[ ]

__/3

MEMORY Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful. Do a recall after 5 minutes.

	TRAIN	EGG	HAT	CHAIR	BLUE
1st trial					
2nd trial					

No points

ATTENTION Read list of digits (1 digit/ sec.).
Subject has to repeat them in the forward order [ ] 5 4 1 8 7
Subject has to repeat them in the backward order [ ] 1 7 4 — __/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors
[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B — __/1

Serial 7 subtraction starting at 80 [ ] 73 [ ] 66 [ ] 59 [ ] 52 [ ] 45
4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt** — __/3

LANGUAGE Repeat : She heard his lawyer was the one to sue after the accident. [ ]
The little girls who were given too much candy got stomach aches. [ ] — __/2

Fluency / Name maximum number of words in one minute that begin with the letter B [ ] _____ (N ≥ 11 words) — __/1

ABSTRACTION Similarity between e.g. banana - orange = fruit [ ] eye – ear [ ] trumpet – piano — __/2

DELAYED RECALL

	Has to recall words **WITH NO CUE**	TRAIN [ ]	EGG [ ]	HAT [ ]	CHAIR [ ]	BLUE [ ]	Points for UNCUED recall only
Optional	Category cue						
	Multiple choice cue						

__/5

ORIENTATION [ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City — __/6

Adapted by : Z. Nasreddine MD, N. Phillips PhD, H. Chertkow MD
© Z.Nasreddine MD www.mocatest.org

Normal ≥ 26 / 30

TOTAL __/30
Add 1 point if ≤ 12 yr edu

Administered by: _____

*Afrikaans translations were used for Afrikaans participants

APPENDIX F

PATIENT HEALTH QUESTIONNAIRE (PHQ-9)

NAME:_____ DATE:_____

Over the last *2 weeks,* how often have you been bothered by any of the following problems?
(use "✓" to indicate your answer)

	Not at all	Several days	More than half the days	Nearly every day
1. Little interest or pleasure in doing things	0	1	2	3
2. Feeling down, depressed, or hopeless	0	1	2	3
3. Trouble falling or staying asleep, or sleeping too much	0	1	2	3
4. Feeling tired or having little energy	0	1	2	3
5. Poor appetite or overeating	0	1	2	3
6. Feeling bad about yourself—or that you are a failure or have let yourself or your family down	0	1	2	3
7. Trouble concentrating on things, such as reading the newspaper or watching television	0	1	2	3
8. Moving or speaking so slowly that other people could have noticed. Or the opposite — being so figety or restless that you have been moving around a lot more than usual	0	1	2	3
9. Thoughts that you would be better off dead, or of hurting yourself	0	1	2	3
add columns		+	+	
TOTAL:				

(Healthcare professional: For interpretation of TOTAL, please refer to accompanying scoring card).

10. If you checked off *any problems,* how *difficult* have these problems made it for you to do your work, take care of things at home, or get along with other people?

- Not difficult at all _____
- Somewhat difficult _____
- Very difficult _____
- Extremely difficult _____

A2663B 10-04-2005

APPENDIX G

ACTIVITY-SPECIFIC BALANCE CONFIDENCE SCALE

Date: _____ **Test number:_____**

Participant Code:_____

Instructions: Please indicate your level of confidence in doing each activity without losing your balance or becoming unsteady.

- 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 or hold onto someone to do the activity, rate your confidence as if you are using these supports.

For <u>each</u> 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 floor? _____%
4. …reach for a small can off a shelf at eye level? _____%
5. …stand on your tip toes 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 the 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. …bump 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 and not the railing? _____%
16. …walk outside on slippery walkways? _____%

TOTAL RATING:_____ ÷ 16 = ABC SCORE:_____

roneg25@gmail.com

APPENDIX H

PARKINSON'S DISEASE QUESTIONNAIRE – 39

Date: _____ **Test number:_____**

Participant Code:_____

Instructions: Please tick one box for each of the following items. Due to having Parkinson's disease, how often during the last month have you…

	Item	Never	Occasionally	Sometimes	Often	Always / cannot do at all
1	**Had difficulty doing the leisure activities which you would like to?**	☐	☐	☐	☐	☐
2	**Had difficulty looking after your home, e.g. DIY, housework, cooking?**	☐	☐	☐	☐	☐
3	**Had difficulty carrying bags of shopping?**	☐	☐	☐	☐	☐
4	**Had problems walking 800 meters?**	☐	☐	☐	☐	☐
5	**Had problems walking a kilometre?**	☐	☐	☐	☐	☐
6	**Had problems getting around the house as easily as you would like?**	☐	☐	☐	☐	☐
7	**Had difficulty getting around in public?**	☐	☐	☐	☐	☐
8	**Needed someone else to accompany you when you went out?**	☐	☐	☐	☐	☐
9	**Felt frightened or worried about falling over in public?**	☐	☐	☐	☐	☐
10	**Been confined to the house more than you would like?**	☐	☐	☐	☐	☐
11	**Had difficulty washing yourself?**	☐	☐	☐	☐	☐
12	**Had difficulty dressing yourself?**	☐	☐	☐	☐	☐

roneg25@gmail.com

Due to having Parkinson's disease, how often during the last month have you…

	Item	Never	Occasionally	Sometimes	Often	Always / cannot do at all
13	**Had problems doing up your shoe laces?**	☐	☐	☐	☐	☐
14	**Had problem writing clearly?**	☐	☐	☐	☐	☐
15	**Had difficulty cutting up your food?**	☐	☐	☐	☐	☐
16	**Had difficulty holding a drink without spilling it?**	☐	☐	☐	☐	☐
17	**Felt depressed?**	☐	☐	☐	☐	☐
18	**Felt isolated and lonely?**	☐	☐	☐	☐	☐
19	**Felt weepy or tearful?**	☐	☐	☐	☐	☐
20	**Felt angry or bitter?**	☐	☐	☐	☐	☐
21	**Felt anxious?**	☐	☐	☐	☐	☐
22	**Felt worried about your future?**	☐	☐	☐	☐	☐
23	**Felt you had to conceal your Parkinson's from people?**	☐	☐	☐	☐	☐
24	**Avoided situations which involve eating or drinking in public?**	☐	☐	☐	☐	☐
25	**Felt embarrassed in public due to having Parkinson's disease?**	☐	☐	☐	☐	☐
26	**Felt worried by other people's reaction to you?**	☐	☐	☐	☐	☐
27	**Had problems with your close personal relationships?**	☐	☐	☐	☐	☐

roneg25@gmail.com

Comparison between Forward and Backward Gait Retraining for Mobility in individuals with mild to moderate Parkinson's disease

Due to having Parkinson's disease, how often during the last month have you…

	Item	Never	Occasionally	Sometimes	Often	Always / cannot do at all
28	**Lacked support in the ways you need from your spouse or partner? Do not have a spouse or partner – tick here** □	☐	☐	☐	☐	☐
29	**Lacked support in the ways you need from your family or close friends?**	☐	☐	☐	☐	☐
30	**Unexpectedly fallen asleep during the day?**	☐	☐	☐	☐	☐
31	**Had problems with your concentration, e.g. when reading or watching TV?**	☐	☐	☐	☐	☐
32	**Felt your memory was bad?**	☐	☐	☐	☐	☐
33	**Had distressing dreams or hallucinations?**	☐	☐	☐	☐	☐
34	**Had difficulty with your speech?**	☐	☐	☐	☐	☐
35	**Felt unable to communicate with people properly?**	☐	☐	☐	☐	☐
36	**Felt ignored by people?**	☐	☐	☐	☐	☐
37	**Had painful muscle cramps or spasms?**	☐	☐	☐	☐	☐
38	**Had aches and pains in your joints or body?**	☐	☐	☐	☐	☐
39	**Felt unpleasantly hot or cold?**	☐	☐	☐	☐	☐

*Please check that you have ticked **one box for each question.**

THANK YOU FOR COMPLETING THE PDQ-39

roneg25@gmail.com

APPENDIX I

FREEZING OF GAIT QUESTIONNAIRE

Date: _____ **Test number:_____**

Participant Code:_____

Instructions: Please select the option that most closely relates to your current abilities and fill the number in the block on the right hand side, at the end of each question.

1. **During your <u>worst</u> state – do you walk:**
   - 0 – Normally
   - 1 – Almost normally, somewhat slow
   - 2 – Slow, but fully independent
   - 3 – Need assistance or walking aid
   - 4 – Unable to walk

   ☐

2. **Are your gait difficulties affecting your daily activities and independence?**
   - 0 – Not at all
   - 1 – Mildly
   - 2 – Moderately
   - 3 – Severely
   - 4 – Unable to walk

   ☐

3. **Do you feel that your feet get glued to the floor while walking, making a turn or when trying to initiate walking (freezing)?**
   - 0 – Never
   - 1 – Very rarely; about once a month
   - 2 – Rarely; about once a week
   - 3 – Often; about once a day
   - 4 – Always; whenever walking

   ☐

 roneg25@gmail.com

4. **How long is your <u>longest</u> freezing episode?**

   0 – Never happened

   1 – 1-2 seconds

   2 – 3-10 seconds

   3 – 11-30 seconds

   4 – Unable to walk for more than 30 seconds

   ☐

5. **How long is your typical <u>start hesitation</u> episode (freezing when initiating the first step)?**

   0 – None

   1 – Takes longer than 1 second to start walking

   2 – Takes longer than 3 seconds to start walking

   3 – Takes longer than 10 seconds to start walking

   4 – Takes longer than 30 seconds to start walking

   ☐

6. **How long is your typical <u>turning hesitation</u> (freezing when turning)?**

   0 – None

   1 – Resume turning in 1-2 seconds

   2 – Resume turning in 3-10 seconds

   3 – Resume turning in 11-30 seconds

   4 – Unable to resume turning for more than 30 seconds

   ☐

TOTAL SCORE: _____

THE END

THANK YOU FOR COMPLETING THE FOG-Q

roneg25@gmail.com

APPENDIX J

UPDRS II – Motor Aspects of Experiences of Daily Living

Date: _____ **Test number:_____**

Participant Code:_____

Instructions: Please circle one option (0, 1, 2, 3 or 4) for each of the following items.

1. Over the past week, have you had problems with your speech?

0: Normal: Not at all (no problems).

1: Slight: My speech is soft, slurred or uneven, but it does not cause others to ask me to repeat myself.

2: Mild: My speech causes people to ask me to occasionally repeat myself, but not daily.

3: Moderate: My speech is unclear enough that others ask me to repeat myself every day even though most of my speech is understood.

4: Severe: Most or all of my speech cannot be understood.

2. Over the past week, have you had too much saliva while you're awake or asleep?

0: Normal: Not at all (no problems).

1: Slight: I have too much saliva, but do not drool.

2: Mild: I have some drooling during sleep, but none when I am awake.

3: Moderate: I have some drooling when I am awake, but I usually do not need tissues or a handkerchief.

4: Severe: I have so much drooling that I regularly need to use tissues or a handkerchief to protect my clothes.

3. Over the past week, have you had problems swallowing pills or eating meals? Do you need your pills cut or crushed or your meals to be made soft, chopped or blended to avoid choking?

0: Normal: No problems.

1: Slight: I am aware of slowness in my chewing or increased effort at swallowing, but I do not choke or need to have my food specially prepared.

2: Mild: I need to have my pills cut or my food specially prepared because of chewing or swallowing problems, but I have not choked over the past week.

3: Moderate: I choked at least once in the past week.

4: Severe: Because of chewing and swallowing problems, I need a feeding tube.

 roneg25@gmail.com

4. Over the past week, have you usually had troubles handling your food and using eating utensils? For example, do you have trouble handling finger foods or using forks, knifes, spoons, chopsticks?

0: Normal: Not at all (No problems).

1: Slight: I am slow, but I do not need any help handling my food and have not had food spills while eating.

2: Mild: I am slow with my eating and have occasional food spills. I may need help with a few tasks such as cutting meat.

3: Moderate: I need help with many eating tasks but can manage some alone.

4: Severe: I need help for most or all eating tasks.

5. Over the past week, have you usually had problems dressing? For example, are you slow or do you need help with buttoning, using zippers, putting on or taking off your clothes or jewellery?

0: Normal: Not at all (no problems).

1: Slight: I am slow but I do not need help.

2: Mild: I am slow and need help for a few dressing tasks (buttons, bracelets).

3: Moderate: I need help for many dressing tasks.

4: Severe: I need help for most or all dressing tasks.

6. Over the past week, have you usually been slow or do you need help with washing, bathing, shaving, brushing teeth, combing your hair or with other personal hygiene?

0: Normal: Not at all (no problems).

1: Slight: I am slow but I do not need any help.

2: Mild: I need someone else to help me with some hygiene tasks.

3: Moderate: I need help for many hygiene tasks.

4: Severe: I need help for most or all of my hygiene tasks.

7. Over the past week, have people usually had trouble reading your handwriting?

0: Normal: Not at all (no problems).

1: Slight: My writing is slow, clumsy or uneven, but all words are clear.

2: Mild: Some words are unclear and difficult to read.

3: Moderate: Many words are unclear and difficult to read.

4: Severe: Most or all words cannot be read.

 roneg25@gmail.com

8. Over the past week, have you usually had trouble doing your hobbies or other things that you like to do?

0: Normal: Not at all (no problems).
1: Slight: I am a bit slow but do these activities easily.
2: Mild: I have some difficulty doing these activities.
3: Moderate: I have major problems doing these activities, but still do most.
4: Severe: I am unable to do most or all of these activities.

9. Over the past week, do you usually have trouble turning over in bed?

0: Normal: Not at all (no problems).
1: Slight: I have a bit of trouble turning, but I do not need any help.
2: Mild: I have a lot of trouble turning and need occasional help from someone else.
3: Moderate: To turn over I often need help from someone else.
4: Severe: I am unable to turn over without help from someone else.

10. Over the past week, have you usually had shaking or tremor?

0: Normal: Not at all. I have no shaking or tremor.
1: Slight: Shaking or tremor occurs but does not cause problems with any activities.
2: Mild: Shaking or tremor causes problems with only a few activities.
3: Moderate: Shaking or tremor causes problems with many of my daily activities.
4: Severe: Shaking or tremor causes problems with most or all activities.

11. Over the past week, have you usually had trouble getting out of bed, a car seat, or a deep chair?

0: Normal: Not at all (no problems).
1: Slight: I am slow or awkward, but I usually can do it on my first try.
2: Mild: I need more than one try to get up or need occasional help.
3: Moderate: I sometimes need help to get up, but most times I can still do it on my own.
4: Severe: I need help most or all of the time.

roneg25@gmail.com

12. Over the past week, have you usually had problems with balance and walking?

0: Normal: Not at all (no problems).

1: Slight: I am slightly slow or may drag a leg. I never use a walking aid.

2: Mild: I occasionally use a walking aid, but I do not need any help from another person.

3: Moderate: I usually use a walking aid (cane, walker) to walk safely without falling. However, I do not usually need the support of another person.

4: Severe: I usually use the support of another person to walk safely without falling.

13. Over the past week, on your usual day when walking, do you suddenly stop or freeze as if your feet are stuck to the floor.

0: Normal: Not at all (no problems).

1: Slight: I briefly freeze but I can easily start walking again. I do not need help from someone else or a walking aid (cane or walker) because of freezing.

2: Mild: I freeze and have trouble starting to walk again, but I do not need someone's help or a walking aid (cane or walker) because of freezing.

3: Moderate: When I freeze I have a lot of trouble starting to walk again and, because of freezing, I sometimes need to use a walking aid or need someone else's help.

4: Severe: Because of freezing, most or all of the time, I need to use a walking aid or someone's help.

Please check that you have selected **one option for each question.**

This completes the questionnaire. We may have asked about problems you do not even have, and may have mentioned problems that you may never develop at all. Not all patients develop all these problems, but because they can occur, it is important to ask all the questions to every patient.

THANK YOU FOR COMPLETING THE UPDRS PART II

TOTAL SCORE (To be completed by researcher): _____

 roneg25@gmail.com

APPENDIX K

INTRINSIC MOTIVATION INVENTORY

Participant Code:_____ **Date:** _____

Instructions: Please reflect on the exercise program you followed over the past few weeks. For each of the following items, please rate your experience of the program by choosing a corresponding number from the following rating scale:

1 2 3 4 5 6 7

Not true Somewhat true Very true

	Item	Scale						
1	I enjoyed this exercise program very much.	1	2	3	4	5	6	7
2	I think I am pretty good at the exercises.	1	2	3	4	5	6	7
3	I put a lot of effort into the exercises.	1	2	3	4	5	6	7
4	I was very relaxed while doing the exercises.	1	2	3	4	5	6	7
5	I believe the exercises could be of some value to me.	1	2	3	4	5	6	7
6	The exercises were fun to do.	1	2	3	4	5	6	7
7	I am satisfied with my performance of the exercises.	1	2	3	4	5	6	7
8	I tried very hard while doing the exercises.	1	2	3	4	5	6	7
9	I was anxious while doing these exercises.	1	2	3	4	5	6	7
10	I think that doing these exercises is good for my health and fitness.	1	2	3	4	5	6	7
11	I thought the exercises were boring.	1	2	3	4	5	6	7
12	I think I was pretty skilled at the exercises.	1	2	3	4	5	6	7
13	I didn't put much energy into the exercises.	1	2	3	4	5	6	7
14	I felt pressured while doing the exercises.	1	2	3	4	5	6	7
15	I believe doing the exercises could be beneficial to me.	1	2	3	4	5	6	7
16	I thought the exercises were quite enjoyable.	1	2	3	4	5	6	7
17	These are exercises that I couldn't do very well.	1	2	3	4	5	6	7
18	It was important to me to do well at the exercise.	1	2	3	4	5	6	7
19	I did not feel nervous at all while doing the exercises.	1	2	3	4	5	6	7
20	I would be willing to do the exercises again as they have some value to me.	1	2	3	4	5	6	7

TOTAL SCORE (To be completed by researcher):_____

roneg25@gmail.com

APPENDIX L

LIST OF FORMULAS

PD-type differentiation ratio by means of the MDS-UPDRS (Stebbins et al. 2013):

$$\bar{x}_1 = \frac{2.10+3.15a+3.15b+3.16a+3.16b+3.17a+3.17b+3.17c+3.17d+3.17e+3.18}{11}$$

$$\bar{x}_2 = \frac{2.12 + 2.13 + 3.10 + 3.11 + 3.12}{5}$$

Differentiating ration = $\frac{\bar{x}_1}{\bar{x}_2}$

Interpretation:

- ≥1.15 = Tremor Dominant
- ≤0.90 = Postural Instability and Gait Difficulty
- 0.90 – 1.15 = indeterminate

Individual PD symptom scores (Ganesan et al. 2015):

- Bradykinesia = UPDRS III 3.4, 3.5, 3.6, 3.7
- Rigidity = UPDRS III 3.3
- Tremor = UPDRS III 3.15, 3.16, 3.17, 3.18
- Axial involvement (Postural instability and gait) = 3.10, 3.11, 3.12

PDQ-39 Domains

$$Domain\ score = \frac{sumed\ score\ of\ domain}{4 \times x} \times 100$$

Mobility ($x = 10$): 1-10

Activities of daily living ($x = 6$): 11-16

Emotional well-being ($x = 6$): 17-22

Stigm ($x = 4$)a: 23-26

roneg25@gmail.com

Social support ($x = 3$): 27-29

Cognition ($x = 4$): 30-33

Communication ($x = 3$): 34-36

Bodily discomfort ($x = 3$): 37-39

Gait variability

$$Coefficient\ of\ variance\ (CoV) = \frac{Standard\ deviation}{mean} \times 100$$

Gait asymmetry (Plotnik et al. 2005)

1. For each participant, determine which limb had the shorter and longer mean swing times (or step duration) – SSWT and LSWT, respectively.

2. Calculate gait asymmetry: $\ln \frac{SSWT}{LSWT}$

Dual task cost

$$\%\ Dual\ task\ cost\ (DTC) = \frac{(DT\ performance - ST\ performance)}{ST\ performance} \times 100$$

roneg25@gmail.com

APPENDIX M

UNIVERSITEIT·STELLENBOSCH·UNIVERSITY
jou kennisvennoot • your knowledge partner

Approval Notice
Response to Modifications- (New Application)

23-Mar-2016
Grobbelaar, Ron? R

Ethics Reference #: **S16/01/004**

Title: **Comparison between Forward and Backward Gait Retraining for Mobility in individuals with mild to moderate Parkinson's disease.**

Dear Miss Ron? Grobbelaar,

The **Response to Modifications -** ***(New Application)*** received on **29-Feb-2016**, was reviewed by members of **Health Research Ethics Committee 1** via Expedited review procedures on **23-Mar-2016** and was approved.
Please note the following information about your approved research protocol:

Protocol Approval Period: **23-Mar-2016 -22-Mar-2017**

Please remember to use your **protocol number** (**S16/01/004**) on any documents or correspondence with the HREC concerning your research protocol.

Please note that the HREC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

After Ethical Review:
Please note a template of the progress report is obtainable on www.sun.ac.za/rds and should be submitted to the Committee before the year has expired. The Committee will then consider the continuation of the project for a further year (if necessary). Annually a number of projects may be selected randomly for an external audit.
Translation of the consent document to the language applicable to the study participants should be submitted.

Federal Wide Assurance Number: 00001372
Institutional Review Board (IRB) Number: IRB0005239

The Health Research Ethics Committee complies with the SA National Health Act No.61 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 Part 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health).

Provincial and City of Cape Town Approval

Please note that for research at a primary or secondary healthcare facility permission must still be obtained from the relevant authorities (Western Cape Department of Health and/or City Health) to conduct the research as stated in the protocol. Contact persons are Ms Claudette Abrahams at Western Cape Department of Health (healthres@pgwc.gov.za Tel: +27 21 483 9907) and Dr Helene Visser at City Health (Helene.Visser@capetown.gov.za Tel:

+27 21 400 3981). Research that will be conducted at any tertiary academic institution requires approval from the relevant hospital manager. Ethics approval is required BEFORE approval can be obtained from these health authorities.

We wish you the best as you conduct your research.
For standard HREC forms and documents please visit: www.sun.ac.za/rds

If you have any questions or need further assistance, please contact the HREC office at 0219389657.

Included Documents:

Declaration K Welman
CV K Welman
CV E Atterbury
Declaration R Venter
20160307 MOD Protocol
Application form signature page
Protocol
20160307 MOD Letter of Response
Declaration C Walker
CV R Grobbelaar
Application form
Questionnaire Hamilton Rating Scale for Depression
Protocol Synopsis
Payment instruction form
Declaration R Grobbelaar
20160307 HREC Modifications Required letter
20160307 MOD Questionnaires
20160307 MOD ICF
Participant information leaflet & consent form
CV C Walker
Marketing material
Declaration E Atterbury
Questionnaire PAR-Q & You
Checklist
CV R Venter

Sincerely,

Franklin Weber
HREC Coordinator
Health Research Ethics Committee 1

APPENDIX N

Turnitin Originality Report
Roné Grobbelaar Thesis by Roné Grobbelaar
[via Karen Welman]
From Turnitin Sandbox Submission 1 (Moodle TT) (Science Teaching and Learning Discussion Forum (Moodle TT))

- Processed on 07-Nov-2016 11:20 SAST
- ID: 733302394
- Word Count: 88653

Similarity Index
6%

Similarity by Source
Internet Sources: 6%
Publications: 3%
Student Papers: 3%

APPENDIX O Summary of main- and interaction-effects

Table O1 Summary of main- and interaction-effects of descriptive variables

Variable	G	T	GxT
Hoehn & Yahr	0.23	**0.02**	0.25
Unified Parkinson's Disease Rating scale (UPDRS) Part III	0.27	**<0.01**	0.87
Bradykinesia sub-score	0.87	**<0.01**	0.37
Tremor sub-score	0.51	**0.02**	0.27
Rigidity sub-score	**0.04**	**0.01**	0.76
PIGD sub-score	0.27	0.10	0.54
Montreal Cognitive Assessment	0.11	0.84	0.32
Patient Health Questionnaire – 9	0.95	**0.04**	0.81
UPDRS Part II	0.75	**0.04**	0.28
Activity-specific Balance Confidence scale	0.79	0.13	0.82
Six-minute Walk Test	0.89	**<0.01**	0.99
Freezing of Gait Questionnaire	0.44	**0.03**	0.80
Parkinson's Disease Questionnaire – 39 (PDQ-39) Total score	0.78	0.11	0.72
PDQ-39 Mobility	0.68	**<0.01**	0.43
PDQ-39 ADL	0.58	**<0.01**	0.61
PDQ-39 Emotional Well-being	0.59	**<0.01**	0.65
PDQ-39 Stigma	0.52	**0.01**	0.54
PDQ-39 Social	0.75	**0.02**	0.57
PDQ-39 Cognition	0.88	**0.02**	0.64
PDQ-39 Communication	0.98	**0.01**	0.54
PDQ-39 Bodily Discomfort	0.91	**<0.01**	0.56

Bold values indicate significant variables ($p<0.05$).
Abbreviations: G = Group-effect; T = Time-effect; GxT = Interaction-effect.

roneg25@gmail.com

Table O2 Summary of main- and interaction-effects of outcome variables

Variable	SNGLE TASK			DUAL TASK			% DUAL TASK COST		
	G	T	GxT	G	T	GxT	G	T	GxT
10m Walk Test									
Total duration	0.51	**<0.01**	0.47	0.84	0.15	0.69	0.59	0.25	0.81
Cadence	0.71	**<0.01**	0.27	0.86	0.57	0.80	0.98	0.36	0.69
Cadence CoV	0.66	0.32	0.62	0.59	0.92	0.25	0.95	0.61	0.12
% Double support	0.43	**0.05**	0.50	0.33	0.43	0.27	0.83	0.50	**0.04**
% Double support CoV	0.38	0.60	0.23	0.62	0.07	0.27	0.65	**0.05**	0.41
Gait cycle time	0.56	**<0.01**	0.65	0.58	0.47	0.37	0.85	0.36	0.15
Gait cycle time CoV	0.52	0.32	0.44	0.54	0.63	0.39	0.97	0.63	0.12
Gait speed	0.33	**<0.01**	0.35	0.40	**0.02**	0.10	0.85	0.76	**0.02**
Gait speed CoV	0.94	0.50	0.08	0.87	0.61	0.06	0.98	0.50	0.23
Gait speed (%S)	0.24	**<0.01**	0.31	0.52	**0.01**	0.12	0.85	0.76	**0.02**
Step duration GA	0.26	0.41	0.76	0.57	0.67	0.58	0.26	0.33	0.39
Stride length	0.44	**<0.01**	0.68	0.74	**<0.01**	0.32	0.69	**0.05**	0.12
Stride length CoV	0.39	0.28	0.06	0.07	0.89	0.12	0.11	0.16	0.44
Stride length (%S)	0.29	**<0.01**	0.60	0.61	**<0.01**	0.34	0.69	**0.05**	0.12
Swing time GA	0.92	0.32	0.64	0.59	0.56	0.54	0.55	0.21	**0.03**
5x Sit-to-Stand test									
Total duration	0.14	**0.02**	0.12	0.25	0.88	0.32	0.79	0.14	0.71
Stand duration	0.82	0.83	0.86	0.33	0.22	0.21	0.86	0.24	0.40
Timed-Up-and-Go test									
Total duration	0.27	**<0.01**	0.19	**0.08**	**0.09**	0.10	0.39	0.91	0.25
Sit duration	0.51	0.22	0.95	0.41	0.26	0.20	0.89	0.66	0.28
Turn angle	0.90	**0.01**	0.51	0.78	**0.08**	**0.02**	0.89	0.89	0.14
Turn duration	0.16	0.40	0.95	0.17	0.45	0.36	0.68	0.34	0.72
Turn velocity	0.26	**0.01**	0.89	0.52	0.37	0.82	0.96	0.46	0.29

Bold values indicate significant variables ($p<0.05$).
Abbreviations: G = Group-effect; T = Time-effect; GxT = Interaction-effect; CoV = Coefficient of variance; %S = percentage stature; GA = gait asymmetry.

roneg25@gmail.com

APPENDIX P1 Gait & Posture journal submission letter

Article 1 submission: Submission

-----Original Message-----
From: eesserver@eesmail.elsevier.com on Behalf Of Gait & Posture
Sent: 18 January 2017 10:34 AM
To: Roné Grobbelaar <roneg25@gmail.com>
Subject: A manuscript number has been assigned to your submission

Ms. Ref. No.: GAIPOS-D-17-00037
Title: Backward compared to forward over ground gait retraining have additional benefits for gait in individuals with mild to moderate Parkinson's disease: a randomized controlled trial
Gait and Posture

Dear Ms. Grobbelaar,

Your submission entitled "Backward compared to forward over ground gait retraining have additional benefits for gait in individuals with mild to moderate Parkinson's disease: a randomized controlled trial" has been assigned the following manuscript number: GAIPOS-D-17-00037.

You may check on the progress of your paper by logging on to the Elsevier Editorial System as an author. The URL is http://ees.elsevier.com/gaipos/.

Your username is: roneg25@gmail.com

If you need to retrieve password details, please go to: http://ees.elsevier.com/GAIPOS/automail_query.asp

Thank you for submitting your work to this journal.

Kind regards,

Administrative Support Agent
Administrative Support Agent [17-Jan-11]
Gait and Posture

****

For further assistance, please visit our customer support site at http://help.elsevier.com/app/answers/list/p/7923. Here you can search for solutions on a range of topics, find answers to frequently asked questions and learn more about EES via interactive tutorials. You will also find our 24/7 support contact details should you need any further assistance from one of our customer support representatives.

APPENDIX P2 Parkinsonism and Related Disorders journal submission letter

Article 1 submission: Submission

-----Original Message-----
From: eesserver@eesmail.elsevier.com on Parkinsonism & Related Disorders
Sent: 25 January 2017 12:49 AM
To: Roné Grobbelaar <roneg25@gmail.com>
Subject: A manuscript number has been assigned to your submission

Ms. Ref. No.: PARKRELDIS-D-17-00062
Title: Forward compared to backward over ground gait retraining for improved postural transitions and turning in mild to moderate Parkinson's disease: a randomized controlled trial
Parkinsonism & Related Disorders

Dear Ms. Grobbelaar,

Please do not respond to this email by using the reply button.

Your submission entitled "Forward compared to backward over ground gait retraining for improved postural transitions and turning in mild to moderate Parkinson's disease: a randomized controlled trial" has been assigned the following manuscript number: PARKRELDIS-D-17-00062.

You may check on the progress of your paper by logging on to the Elsevier Editorial System as an author. The URL is http://ees.elsevier.com/parkreldis/.

Your username is: roneg25@gmail.com
If you need to retrieve password details please go to: http://ees.elsevier.com/parkreldis/automail_query.asp

Thank you for submitting your work to this journal.

Kind regards,

Susan Calne, -RN CM
Editorial Office
Parkinsonism & Related Disorders

****

For further assistance, please visit our customer support site at http://help.elsevier.com/app/answers/list/p/7923. Here you can search for solutions on a range of topics, find answers to frequently asked questions and learn more about EES via interactive tutorials. You will also find our 24/7 support contact details should you need any further assistance from one of our customer support representatives.