Somatosensory training for postural control in independent-living individuals with Parkinson's disease

by

Tania Gregory

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

Supervisor: Dr. K.E. Welman

December 2015

Declaration

I, Tania Gregory, hereby declare that the information in this thesis is my original work, that I am the owner of the copyright thereof (unless to the extent explicitly otherwise stated). I have not previously submitted its entirety or in part for obtaining a qualification from any other Institution. However, this is an article-format thesis and therefore some of the chapters may be submitted for publication to peer-review journals.

December 2015

Abstract

Somatosensory training for postural control in independent-living individuals with Parkinson's disease

Department of Sport Science,
University of Stellenbosch,
Private Bag X1, Matieland 7602, South Africa.

Thesis: MSc (Sport Science)

December 2015

Introduction: Postural control (PC) impairments in Parkinson's disease (PD) involve proprioceptive processing and integration deficits. Although deficits in proprioception have a negative effect on PC, the precise contribution to postural instability in PD remains unclear. The somatosensory system incorporates both the proprioceptive and haptic feedback systems, and by applying light touch postural sway (PS) can be improved in individuals with PD. The study therefore aimed to determine if an eight-week somatosensory training program (SSTP) would influence PC in individuals with mild to moderate PD.

Study design: Time-series experimental study design.

Methods: Thirty-seven participants with idiopathic PD (67±9 years; H&Y: 2 ± 1; MDS-UPDRS III: 28 ± 14) were divided into two groups i.e. somatosensory training group (EXP; n = 24) and placebo group (PBO; n = 13). Primary outcome measures included joint position sense (JPS), sensory integration (mCTSIB), Timed-Up-and-Go (TUG), fear of falling (FES-I) and PS. Secondary outcome measures were quality of life (PDQ-39 SI), part II, III and total score of Movement Disorder Society-Unified Parkinson's Disease Rating Scale (MDS-UPDRS) and balance confidence (ABC). Participants were tested on medication, at baseline, pre- and post-intervention over a period of 16-weeks. JPS was tested at the ankle joint with the Active Movement Extent Discrimination Apparatus (AMEDA) at 10°, 11°, 12°, 13° and 14°. For the modified Clinical Test of Sensory Integration and Balance (mCTSIB) and PS with and without haptic feedback, the Instrumented Sway tri-axial accelerometer was used to assess overall PS during eight conditions i.e. eyes open (EO),

eyes closed (EC), both off and on a foam pad (+F) as well as all four conditions with haptic feedback.

Results: A statistically significant treatment effect was found in the EC+F ($p = 0.0002$), TUG ($p = 0.0001$), FES-I ($p = 0.02$), part III ($p = 0.02$), as well as in total score of MDS-UPDRS ($p = 0.02$) for the EXP group. The EXP group improved in JPS ($p = 0.02$), EC+F JERK ($p = 0.002$) and RMS ($p = 0.01$) as well as PDQ-39 SI ($p = 0.03$) after the intervention. The EXP group showed a significant improvement in the TUG before and after the Treatment phase ($p < 0.05$). The EXP group also showed a significant improvement for EC+F JERK ($p = 0.002$) and TUG ($p = 0.01$), with a strong tendency for better balance confidence ($p = 0.07$), compared to the PBO group. Both groups presented with reduced sway amplitude when receiving haptic feedback compared to no manual contact, regardless of the surface area ($p < 0.01$). However, no group differences were found during the Baseline and Treatment phase ($p > 0.05$).

Conclusion: The positive findings of this study provide evidence that this SSTP could improve PC in PD individuals. However, haptic feedback cannot be altered by a SSTP, but it can improve PS in individuals with PD, regardless of the surface area.

Uittreksel

Somatosensoriese oefening vir posturale beheer in onafhanklike individue met Parkinson's siekte

("Somatosensory training for postural control in independent-living individuals with Parkinson's disease ")

Departement Sportwetenskap,
Universiteit van Stellenbosch,
Privaatsak X1, Matieland 7602, Suid Afrika.

Tesis: MSc (Sportwetenskap)

Desember 2015

Inleiding: Posturale beheer (PB) beperkinge in Parkinson's siekte (PS) betrek tekortkominge in proprioseptiewe prossessering en integrasie. Alhoewel tekortkominge in propriosepsie 'n negatiewe effek het op PB, is die presiese bydrae daarvan op posturale onstabiliteit onbekend. Ligte aanraking verbeter posturale wieg (PW) in individue met PS, maar meer navorsing oor effektiewe oefenprogram ontwikkeling om PB te verbeter word benodig. Die doel van hierdie studie was om vas te stel of 'n agt-weke somatosensoriese oefenprogram (SSOP) PB kan beïnvloed in individue met ligte tot matige PS.

Studie ontwerp: Tyd-reeks eksperimentele studie ontwerp.

Metodes: Sewe-en-dertig deelnemers met idiopatiese PS (67 ± 9 jaar; H&Y: 2 ± 1; *MDS-UPDRS* III: 28 ± 14) was in twee groepe ingedeel naamlik, somatosensoriese oefengroep (EXP; n = 24) en placebo groep (PBO; n = 13). Primêre uitkoms maatreëls het gewrigsposisie (GP), sensoriese integrasie (*mCTSIB*), Staan-Op-en-Stap (SOS), vrees vir val (*FES-I*) en PW ingesluit. Sekondêre uitkoms maatreëls was kwaliteit van lewe (*PDQ-39 SI*), gedeelte II, III en totale telling van die *Movement Disorder Society-Unified Parkinson's Disease Rating Scale (MDS-UPDRS)* asook balans selfvertroue (*ABC*). Toetsing het plaasgevind terwyl die deelnemers op medikasie was vir basislyn, voor- en na-intervensie oor 'n periode van 16-weke. Gewrigsposisie was getoets by die enkelgewrig deur die *Active Movement Extent Discrimination Apparatus (AMEDA)* by 10°, 11°, 12°, 13° and 14°. Vir die *modified Clinical Test of Sensory Integration and Balance (mCTSIB)* en PW met en sonder haptiese

terugvoer, is die *Instrumented Sway (ISway)* tri-aksiale versneller gebruik om algehele PW (JERK, RMS en CF) te assesseer tydens agt verskillende kondisies naamlik, oë oop (OO), oë toe (OT), beide op die vloer en op 'n balansmaatjie (+BM), asook al vier kondisies met haptiese terugvoer.

Resultate: 'n Statisties betekenisvolle behandeling effek was gevind in OT+BM ($p = 0.0002$), SOS ($p = 0.0001$), vrees vir val ($p = 0.02$), gedeelte III ($p = 0.02$) asook totale telling van *MDS-UPDRS* ($p = 0.02$) vir die EXP groep. Die EXP groep het verbeter in GP ($p = 0.02$), OT+BM JERK ($p = 0.002$) en RMS ($p = 0.01$) asook kwaliteit van lewe ($p = 0.03$) na die Behandelingsfase. Die EXP groep het statisties betekenisvol verbeter voor en na die Behandelingsfase in die SOS ($p < 0.05$). Addisioneel was daar 'n statisties betekenisvolle groepverskil na die intervensie vir OT+BM ($p = 0.002$), SOS ($p = 0.01$) asook 'n sterk tendens vir 'n groepverskil in balans selfvertroue ($p = 0.07$), waar die EXP groep verbeterde resultate aangedui het in vergelyking met die PBO groep. Beide groepe het minder posturale amplitude aangedui wanneer haptiese terugvoer tot beskikking was teenoor geen aanraking nie, ongeag van die vloer oppervlakte. Alhoewel, geen groep verskille is gevind tydens die Basislyn en Behandelingsfase nie.

Gevolgtrekking: Die positiewe bevindinge van hierdie studie voorsien bewys dat die SSOP, PB in individue met PS kan verbeter. Haptiese terugvoer kan nie beïnvloed word deur 'n SSOP nie, maar dit kan PW verbeter in individue met PS, ongeag van die oppervlakte.

Acknowledgements

I would like to thank the following people and organisations who all contributed in some way or another to assist in the completion of this study, this thesis would not have been possible without your assistance and guidance.

- My supervisor, Dr. Karen Welman, for your guidance during the preparation of my thesis. It would not have been possible without your countless hours and day-by-day advice and support. Thank you for always putting me at ease and teaching me how to be patient and humble.
- National Research Foundation (South Africa), Harry Crossley Foundation and Ernst and Ethel Eriksen Trust who partly funded this project.
- The research assistants, Aimee Barrett, Claire Walker and Kelello Tswai for all your hard work and endless kilometres you drove to help with data capturing and program execution
- To Michelle Puren and Elizma Atterbury for your help with the execution of the training program.
- To Marie Midcalf, for the shooting and editing of the somatosensory training program DVD as well as Henry Puren for being our filming subject.
- Prof. Martin Kidd, thank you for your assistance with the statistical analysis, and for always being available to explain something just one more time.
- To Mauritz Zastron, you are my rock and my best friend. Thank you for all the hours you spent with me in the library, keeping me motivated and encouraged. Your joyfulness is contagious.
- To my parents, Eugene and Ilze Gregory, and brother, Michael Gregory, for your love, long distance support and ongoing trust and inspiration. I could not have asked for better parents and brother.

- To the rest of my family, thank you for all your love and support as well as for always believing in me. Special thanks to aunty Beryl for proof reading my thesis, the amount of words in this thesis cannot describe how grateful I am.
- Last but not least to the participants who voluntarily participated in this study for your kindness in donating your time. Thank you for making the effort to come to Stellenbosch for the testing or opening your home to us and inviting us in with such love and generosity.

Thank you Lord for providing me with the opportunity to further my knowledge, your love is all consuming and I thank you for the strength you provided me throughout the completion of my thesis.

"For the Lord gives wisdom, and from his mouth come knowledge and understanding." - Proverbs 2:6

Dedications

This thesis is dedicated to my parents Eugene and Ilze, for their uncompromising support, trust and love.

Contents

List of Figures

List of Tables

Abbreviations

ABC:	Activities-specific Balance and Confidence
AMEDA:	Active Movement Extent Discrimination Apparatus
AP:	Anterior-Posterior
BBS:	Berg Balance Scale
BESTest:	Balance Evaluation Systems Test
BMI:	Body Mass Index
CBM:	Community Balance and Mobility assessment
CF:	Centroidal Frequency
CI:	Confidence Intervals
DVD:	Digital Video Disc
EPDA:	The European Parkinson's Disease Association
EXP:	Experimental group
FES-I:	Fall Efficacy Scale - International
GP:	Grooved Pegboard
H&Y:	Hoehn and Yahr scale
IMI:	Intrinsic Motivation Inventory
ISway:	Instrumented Sway
JERK:	Jerkiness
JPS:	Joint position sense
mCTSIB:	modified Clinical Test of Sensory Integration of Balance
MDS-UPDRS:	Movement Disorder Society-Unified Parkinson's Disease Rating Scale
ML:	Medial-Lateral
MoCA:	Montreal Cognitive Assessment
PBO:	Placebo group
PC:	Postural control
PD:	Parkinson's disease
PDQ-39 SI:	Parkinson's Disease Quality of Life Questionnaire Summary Index

POMA:	Performance Oriented Mobility Assessment
PS:	Postural sway
QoL:	Quality of Life
RMS:	Root Mean Square
SAFEx:	Sensory Attention Focused Exercise
SEM:	Standard Error of Mean
SRY:	Sex-Determining Region
SSA:	Sub-Saharan African
SSTP:	Somatosensory Training Program
STST:	Sit-To-Stand Test
SD:	Standard Deviation
TUG:	Timed-Up-and-Go
UPDRS:	Unified Parkinson's Disease Rating Scale
WBV:	Whole-Body Vibration
WHO:	World Health Organisation

Glossary

Base of support: The base of support for standing on a flat, firm surface is defined as the area contained within the perimeter of contact between the surface and the two feet. This area is nearly square when the feet are placed comfortably apart while the person is quietly standing [1].

Centre of gravity: A theoretical point about which the forces of gravity act; a point in humans located in the lower abdominal area of the trunk [2].

Centroidal Frequency: This parameter gives an indication of frequency of sway [3].

Haptic feedback: This is both tactile and kinaesthetic sensory feedback or perception; tactile perception is generally sent through the skin [4].

Independent-living: Individuals who do not live in an institutional setting, but as those who have the ability to live a freely chosen lifestyle in the community [5].

Jerkiness: This is the relative smoothness of postural sway, reflecting the amount of active postural corrections, and is interpreted as a measure of dynamic stability [3].

Kinaesthetic information: This refers to receptors in muscles and tendons that allow a person to feel the position of their body and sense movement [4].

Mild to moderate Parkinson's: Individuals with a severity level of I-III on the Hoehn and Yahr Scale [6] or a score of < 59 on the Movement Disorder Society-Unified Parkinson's Disease Rating Scale (MDS-UPDRS) [7].

Postural control: The maintenance of a person's center of mass within his or her stability limits, which is defined as the person's base of support [8].

Proprioception: The sense of the positioning of body parts in space [9].

Root Mean Square: This parameter gives the amplitude of postural sway movements, or sway area [10].

Sensory-motor: The process whereby the central nervous system integrates sensory input, used for assisting or implementing motor program execution [11].

Sensory-motor interaction: The synergistic relationship between the sensory system and the motor system. The two involve receiving and transmitting the stimuli to the central nervous system where the stimulus is then interpreted. The nervous system then determines how to respond and transmits the instructions via nerve impulses to carry out the instructions [12].

Somatosensory: This system includes both tactile and proprioceptive systems [13].

Somatosensory training: An intervention that focusses on somatosensory signals i.e. proprioception and haptic feedback, without receiving information from the other sensory systems such as the visual and vestibular [14].

Overview

The current thesis followed a research article format and focussed on academic and practical implications of the research conducted, based on the research aims and objectives. The first chapter serves as an introduction concerning the thesis, providing some background information as well as knowledge regarding sensory aspects and fall risk of individuals with Parkinson's disease (PD). Thereafter, Chapter two presents an overview of the literature, focussed on postural control (PC) in general as well as specifically in individuals with PD. This chapter also contains a review on previously conducted exercise interventions that focussed on somatosensory, sensory integration as well as overall balance training. Additionally, the problem statement, research aims and objectives as well as appropriate variables are discussed in Chapter two. Chapter three, four and five each contain a research article, with the actual reporting format derived from the author instructions of the specific journals chosen. Article one was submitted to the *Parkinsonism and Related Disorders*, article two was submitted to the *Gait and Posture* (manuscript number: GAIPOS-D-15-00635) and Article three to *Archives of Physical Medicine and Rehabilitation*. Following Chapter five is the General Discussion and Conclusion (Chapter six), including an understanding on study limitations, recommendations for future research as well as implications for practice and research. Referencing format for the current thesis as well as articles follow the Vancouver (Numeric) referencing style. This document has one reference list, thus articles were adapted accordingly. All necessary documentation can be found in the Appendices attached.

Chapter 1

Introduction

1.1 Background

Parkinson's disease (PD) is a progressive and chronic movement disorder, for which there is no cure to date, that causes an overall reduction in movement. The dopaminergic system innervates a group of brain structures namely the basal ganglia, which functions to promote motor activity [15]. With PD the dopaminergic system is seriously affected, causing the degeneration of neurons that produce dopamine in the basal ganglia [16]. High levels of dopamine leads to high levels of motor activity, whereas low levels of dopamine function, such as seen in PD, demand greater efforts for any given movement [15]. This neurological condition affects around seven to 10 million middle-aged and elderly individuals worldwide [17]. In other words, it is estimated that one person in every 500 people is likely to have PD. Nichols and colleagues [18] stated that PD affects more than 1% of individuals over the age of 55 and 3% of individuals over the age of 75 years old.

Individuals with PD require a high level of continuous care and as the prevalence increases this will present a major challenge to under-resourced and developing countries, such as South Africa. To date, published studies on PD in South Africa are scarce, although some studies have been conducted on Sub-Saharan African (SSA) countries [19]. Sub-Saharan Africa has been defined as those African countries which are fully or partially located south of the Sahara excluding the African Arabic countries [19]. According to Velkoff & Kowal [20], old age is an established risk factor for the development of PD and it is predicted that by 2050 there will be about 139 million people aged 60 years and older in SSA. A review of articles published over a 60-year period between 1944 and 2004 on PD from the entire African continent, revealed a limited number of published studies on prevalence, incidence and genetics [21]. Parkinson's disease management in SSA is a major obstacle at this stage because of the lack of sufficient numbers of neurologists, having a median number

of only three neurologists per 10 million people in the majority of SSA countries [19].

The European Parkinson's Disease Association [22] wrote a special report on PD in South Africa in 2012, stating that South Africa has about 45 million individuals and that around 40 million of these individuals cannot afford a private healthcare plan because they don't have the financial resources. Because of this, individuals have to rely on the availability of doctors in the public sector, thus leading to roughly 25 neurologists that have to bear the responsibility of 40 million people in South Africa. Dopaminergic medication is often insufficient to assist postural instability and therefore non-pharmacological interventions addressing balance problems are important and research is wanted [23]. It has more recently been stated that dopaminergic medication has little or damaging effects on postural sway (PS) for PD individuals with a higher fall risk, but arguably reduces PS for patients with lower fall risk [24]. Balance training could be more sustainable method to address postural impairments in individuals with neurological conditions, given that it usually consists out of low cost, easy to do activities, with limited equipment. The World Health Organisation (WHO) is encouraging researchers to prevent injuries as well as hospitalisation, and balance training could be a successful manner to improve postural control (PC), thus achieving this outcome.

1.2 Sensory Aspects of Parkinson's Disease

Somatosensation is a global term which includes all of the mechanoreceptors, thermoreceptors, and pain information arising from the peripheral nervous system [25]. The somatosensory system includes the processing of proprioceptive, haptic feedback as well as nociceptive information [26].

Postural control, more commonly known as balance, is a complex skill based on the interaction of dynamic sensory-motor processes which allows one to maintain an unsteady equilibrium while the muscles work against gravity [27]. Proprioception plays a big role in the sensory part of sensory-motor control and has been defined as afferent information that arises from sensory receptors, focussed on maintaining PC, active and passive movements, segmental posture as well as resisting certain movements [28, 25]. Researchers further subdivided proprioception into three sensation modalities, namely Joint position sense (JPS), kinesthesia and sense of force [25]. It is the intrinsic feedback mechanism that constitutes of three principal proprioceptors, namely the vestibular system, muscle spindles, Golgi tendon organ and joint receptors, which helps monitor one's own capability to maintain balance [29, 30]. Ongoing research is challenging the traditional view that PD is a pure motor disorder and observations have been made that proprioceptive disturbances could contribute

to balance and motor deficits in PD [31, 32, 33, 34, 35, 36, 37, 38].

Haptic feedback refers to both tactile and kinaesthetic sensory feedback/ perception; tactile perception is generally sent through the cutaneous mechanoreceptors, while kinaesthetic perception refers to receptors in muscles, tendons, and joints that allow a person to feel the position of their body [4, 39]. Haptic sense is the only sense that allows us to interact with the world around us and simultaneously observe these interactions [40]. During early childhood, the haptic sense lays the foundation for the organisation of sensory information for daily use [12], which supplies the basis to increase motor learning even further through the use of haptic interactions [41]. It has been stated that individuals with PD have poor haptic feedback [42]. Haptic feedback has not been shown to be more or less effective compared to other feedback modalities [43]. Most studies done indicating the effectiveness of haptic feedback has mostly come from simple motor task studies, and only a few, complex motor tasks studies, e.g. sports [43]. Nonetheless, it has been shown that haptic feedback enhances the presence as well as the functioning of the user [44], which makes it easier to work with subjects by using this type of feedback. The practice design criteria for successful haptic feedback in individuals with PD need to be elaborated on.

1.3 Fall Risk in Parkinson's Disease

The reduced PC in PD contributes to an increase in falls and injuries. This often results in inactivity that causes a decline in lower body musculoskeletal function [45]. It is well known that falls are a debilitating and costly problem for many people with PD and that recurrent falls are common among these individuals [46]. It has been stated that 60% of individuals with PD fall yearly and that 40% fall recurrently [47]. Falls may result in serious complications, and in worse cases hospitalisation. Given the high incidence of fall-related injuries within this population, on-going assessment of postural stability is important in disease management [48].

Latt et al. [49] investigated cross-sectional studies looking at characteristics associated with history of falling in individuals with PD. It was found that increased age, disease duration, Timed-Up-and-Go (TUG) times, PS as well as more advanced disease state and worse PD symptoms are all related to the history of falling. Furthermore, these researchers identified prospective studies examining risk factors for falls in individuals with PD. Previous falls, cognitive impairment and PD severity measures were all found to be related to an increased risk for falling [49].

Fortunately, exercise has shown to be effective in reducing falls in individuals with PD [47]. Relatively recent studies show that challenging balance exercise significantly reduce falls in individuals with PD, leading to improved functional capacity [50, 51]. Falling can be very debilitating and individuals who have sustained prior falls often develop a fear of renewed falls, aggravating a concurrent loss of mobility [52]. Many negative consequences are associated with loss of mobility, such as a reduced independence, increased weakness and osteoporosis, deterioration of overall fitness as well as an enlarged risk of admittance to hospitals or nursing homes [53]. According to Canning et al. [47], future research is warranted for the development of successful fall reduction programs, which will in turn improve the quality of life (QoL) of individuals with PD.

1.4 Conclusion

Individuals with PD have reduced PC as well as poor somatosensation, both of which are important to reduce fall risk and improve QoL. Furthermore, Parkinsonian individuals have impaired functional mobility leading to an inability to change their balance and gait strategies as the conditions and demands change [54]. The current investigation set out to assess whether an eight-week somatosensory training program (SSTP) will influence JPS, sensory integration, PS, mobility, disease severity as well as reduce fear of falling, improve QoL and balance confidence in individuals with mild to moderate PD. The application of a successful SSTP may improve posture and balance in individuals with PD, as well as give insight whether proprioceptive deficits in individuals with PD could be addressed directly, instead of training other compensatory strategies. It is important to find solutions to these balance and gait impairments to prevent falls and increase QoL.

Chapter 2

Literature Review

2.1 Overview of Postural Control

Balance is the process of maintaining the centre of gravity within the body's base of support, and plays a vital role in the maintenance of static and dynamic equilibrium [55, 56]. The balance system has three functional purposes namely: 1) maintaining specific postural alignment (sitting and standing); 2) facilitating voluntary movements (moving between postures); and 3) reacting to external disturbances (slipping or tripping) [57]. During quiet standing, the body is not entirely still because the centre of mass is continuously moving, which is referred to as PS. Postural sway contributes to balance control and is a representation of a state of complex sensory-motor control loops [54].

Balance stems from several factors with complex interactions, including various neural subsystems, the individual's musculoskeletal systems as well as the individual's task and environmental situation [8]. When referring to the neural and musculoskeletal subsystems that contribute to balance function, the PC system is usually referred to [8]. Postural control is a complex perceptual-motor process that allows an individual to maintain their balance through feedback and feedforward mechanisms from visual, vestibular and somatosensory sensory receptors [58]. The interaction of these sensory systems signal the neuromuscular system to activate postural muscles in response to information from numerous physiological, task and environmental conditions [59, 60]. Consequently, when evaluating balance, the sensory system and its contribution to balance could be very complicated because it consists of many integrated components. The environment around us is filled with various cues, which are selectively picked up by the sensory system through these specialised receptors. These receptors are found in the sensory end organs within the eyes, inner ear (vestibular system), muscle spindles, Golgi tendon organs, cutaneous receptors and joint receptors [61, 29]. Sensory information received through these receptors are then sent to the central nervous system, which filters, compares,

weighs, stores and processes it to determine timing, direction and amplitude for the correct postural action [55].

Horak [27] proposed a Systems Framework for Postural Control, which describes six major components essential for the maintenance of PC (Table 2.1). Balance disorders may be caused by disturbances in any of these domains, leading to an increased chance of falls in the elderly population. As individuals age, there is an associated increased risk for deteriorated balance leading to reduced QoL. Thus, difficulty in one or more these domains could be the source for postural instability [27]. An intact PC system is important for stability as well as for accomplishing activities of daily living safely [57], such as doing dishes, reaching for an object or turning from one position to another. The PC system can be affected by neurological conditions, such as PD, sensory deficits, muscular weakness as well as normal aging [57]. The following sections will take a closer look at the factors which affect PC as well as the effect of PD specifically on the PC system.

Table 2.1: Resources required for postural instability and orientation.

Domains in Systems Framework for Postural Control	Summarised components in each domain
Biomechanical Constraints	Degrees of Freedom, Strength, Limits of Stability
Movement Strategies	Reactive balance, Anticipatory and Voluntary postural strategies
Sensory Strategies	Sensory Integration, Sensory Reweighting
Orientation in Space	Perception, Gravity, Verticality
Control of Dynamics	Gait, Proactive
Cognitive processing	Attention, Learning

Adapted from Horak [27]

2.1.1 Factors Influencing Postural Control

Balance depends on the harmonious interaction of the vestibular, visual, somatosensory, and musculoskeletal system [27]. However, with aging and disease, functional loss in each system can be observed. This hinders motor response implementation responsible for PC maintenance and could lead to increased risk for falls and morbidity due to functional impairment [27, 62]. The causes for falls are said to be multifactorial, which stem from the interaction between factors that render an individual vulnerable to a disease, and

factors that triggers the onset of a disorder [63]. These are referred to as predisposing and precipitating factors respectively, and can further be divided into intrinsic and extrinsic factors [64].

Intrinsic Factors can be described as those that cause impaired functioning of the systems that include PC, diseases, as well as behavioural and cognitive disorders. These factors are related to the individuals themselves, and presents with an inability to sustain or restore PC when necessary [62]. Additionally, the knowledge and experience of the individuals are also important factors since these will indicate how well they adapt to a given environment [65]. For example, an individual who is familiar with slippery surfaces will adapt their gait pattern with more success when compared to an individual who has no prior experience on this given surface area. Falls are also well correlated with attention and multi-tasking, increasing the probability of slipping and tripping as one struggles to generate the correct motor response because of cognitive interference [66, 65].

Extrinsic Factors are defined as those related to an individual's environment, culture, religion, age and ethnic factors [62]. Environmental factors include the circumstances that the individual lives in and is confronted with in everyday living, such as lighting, temperature, walking surface, and high or narrow steps taken [64]. Furthermore, research indicates that an activity itself can also be a risk factor for falling, especially when stability is modified by the type, weight and size of the load being executed [65]. For example, a fall is more likely to occur when an individual is rushing to get to a specific destination while carrying something big in size, as opposed to when walking at a comfortable pace and still carrying a large object.

Gauchard et al. [65] stated the importance of expanding existing knowledge on intrinsic and extrinsic factors influencing PC, because it will allow for a safer environment for individuals as well as occupational conditions for rehabilitation therapists.

2.2 Maintaining Postural Control in Parkinson's Disease

Individuals with PD suffer from locomotor and balance dysfunction, which leads to impaired mobility as well as physical and psychosocial debility [54]. For the purpose of this study, four of the six domains in the Systems Framework for Postural Control proposed by Horak [27] will be highlighted, namely

Biomechanical Constraints, Sensory Strategies, Orientation in Space and Control of Dynamics (Table 2.1), as well as the effect PD has on each domain.

2.2.1 Biomechanical Constraints

Static stability refers to balance during quiet stance and requires the ability to adequately keep the body's centre of mass over its base of support [3]. As PD progresses, postural instability becomes an unavoidable feature and is associated by a decrease in the magnitude of postural responses [67], reduction in the ability to adjust to an anticipatory movement [68] and diminished limits of stability [69]. Size and quality of base of support is the most important biomechanical constraint on balance [27]. Limits of stability or functional stability limits are defined as the ability to move the centre of mass as far as possible in the Anterior-Posterior (AP) or Medial-Lateral (ML) directions within the base of support [70]. The central nervous system can determine how much AP and ML movement is allowed to maintain equilibrium by use of an internal representation, called a cone of stability [27]. Individuals suffering from PD have an abnormal cone of stability representation, contributing to their worsened postural instability [27, 71]. This in turn causes difficulty in managing activities of daily living and increases their risk for falling [51].

Depending on the individuals' limits of stability, more or less PS can be tolerated. Characteristics of PS in individuals with PD include higher velocity, greater frequency as well as larger sway in lateral direction compared to normal controls [54]. In particular, individuals with PD show these characteristics during conditions where vision is absent compared to age-matched controls [3, 72, 54]. Reduced PC leads to an increase in postural instability, which can often result in a significant loss of QoL and life expectancy because of an increased risk of falling, soft tissue injuries, fractures as well as psychological fear of falling [72].

2.2.2 Sensory Strategies

As mentioned earlier, the ability to maintain balance during quiet standing depends on the somatosensory, vestibular and visual systems as well as the integration between these systems [54]. As the environment around an individual changes, the person must adjust the sensory contributions to control balance, which is referred to as sensory reweighting [54]. For example, if a person stands on a firm surface with their eyes closed, they will mainly depend on the somatosensory and vestibular system for balance, whereas on an unstable surface, but with eyes open, a person will shift their sensory input to predominantly the visual system. In other words, based on this Sensory Weighting Hypothesis, it is expected that if one sensory input is absent or inappropriate for the given context, then other more reliable sensory input will provide the

principal information to maintain balance [73].

Individuals with PD present with an inability to rapidly change sensory weighting for different conditions [74]. This is supported by the appearance of reduced PC during conditions where individuals have to stand on an unstable surface with their eyes closed. Researchers state that this phenomenon cannot necessarily be attributed to difficulty with vestibular information use, but to the inability to shift between sensory systems [75, 76]. Furthermore, research shows that individuals with PD, struggle to maintain PC when their eyes are closed, regardless of the surface, because they are visually dependent [77]. Consequently, this could be ascribed to impaired proprioception [78]. Additionally, PD individuals struggle with recognition of small changes in surface orientation, supporting the impaired proprioception belief [79]. Unfortunately, even though Parkinsonian individuals are more reliant on continuous visual information compared to healthy individuals, with aging vision becomes impaired, causing patients to rely on impaired proprioceptive information for sensory feedback [80].

Movement disorders, such as PD, predominantly results from basal ganglia dysfunction, and since this disease shows increased sensory abnormalities, it suggests that the pathophysiology involves the sensory system [81]. Additionally, studies have provided evidence that loss of neurons in the thalamus, which projects to the sensory-motor regions [82, 83], and hyperactivation of the cerebellum, could be the cause of impaired automatic movements [84]. Thus, not only the basal ganglia, but also the cerebellum, thalamus and their connections receive altered sensory information and leads to abnormal sensory-motor integration [81].

2.2.3 Orientation in Space

Healthy individuals automatically alter how the body is orientated in space, depending on gravity, support surface, visual surround and internal references [27]. Verticality is defined as the ability to orient appropriately with respect to gravity [70], which is built up and updated by information from the visual, vestibular and somatosensory systems [85]. Inaccurate representation of verticality could result in postural misalignment with respect to gravity, such as seen in PD, causing increased instability [27, 86]. Parkinsonian individuals have a tendency to present with a forward bent head and trunk, giving origin to a stooped posture, which supports findings of impaired verticality [86]. Additionally, the basal ganglia also play an important role in verticality, further explaining the difficulty Parkinsonian individuals have with maintaining spatial orientation [87].

Somatosensation has been recognised to contribute to body orientation because it has various origins affecting perception of verticality [88, 85]. Since spatial orientation relies on the use of visual, vestibular and proprioceptive sensory information, any discrepancies between these sensory inputs could lead to spatial disorientation. Parkinson's disease individuals present with several subjective sensory symptoms (numbness, coldness etc.) as well as somatosensory deficits, including inadequate proprioception [31, 79] and poor haptic feedback [42]. This has been said to be because of a deficit in processing abilities that occur at the basal ganglia level, and that altered sensory processing contributes to related motor deficits [89]. Individuals with PD have abnormal muscle-stretch reflexes in the upper and lower extremities leading to disturbances in proprioceptive regulation [90]. This is supported by Jacobs & Horak [91], who suggested that individuals with PD suffer from sensory-motor deficits, especially integrating and utilising proprioceptive feedback. It has been stated that individuals with PD have poor haptic feedback [42]; nonetheless, individuals with PD can improve their static PC with unsupportive manual haptic feedback cues [92]. Therefore, using very light unsupportive touch and proprioceptive feedback, posture can be stabilised. It has been suggested that the unsupportive touch provides sensory feedback about body orientation [93, 94, 92].

2.2.4 Control of Dynamics

During walking there is a constant side to side and forward shifting in an individual's centre of mass, which is controlled by foot placement as well as axial control of lateral and forward stability [54]. Placing the swinging limb under the falling centre of mass during gait is defined as forward postural stability, whereas lateral stability comes from combining lateral trunk control and lateral placement of the feet [27]. Impaired mobility is a serious cause of disability for individuals with PD and is marked by the inability to quickly and efficiently adapt movement, balance and postural transition to changing task conditions as well as the environment [95]. A neurologist from the Czech Republic, Dr. Vladimir Janda, stated that it is impossible to separate the sensory and motor system when evaluating human control movement. This leads to the term sensory-motor system, which explains that these two systems function as one unit, thus when changes occur in the one system, adaptation will occur in the other system [96, 97]. The ability to quickly change motor programs with changing environmental conditions as well as the ability to maintain safe mobility during multiple motor and cognitive tasks, depend on an intact sensory-motor system [98, 99, 95]. It is well known that individuals with PD have sensory-motor impairments affecting balance, gait and posture [95].

Motor control depends on constant review and modification from sensory integration, efferent motor commands and resultant movements [25]. As mentioned earlier, individuals with PD have impaired sensory integration, which amplifies the deficits they experience with PC [91]. Foreman and colleagues [100] stated that these deficits form the foundation of postural instability leading to a reduced ability to control the centre of mass within the base of support during mobility and can eventually manifest themselves in falls. A combination of visual and proprioceptive information is necessary for making modifications to an individuals' gait velocity [101, 102]. It is suggested that visual feedback provides information to the central nervous system regarding position and movement of body segments in relation to one another and the environment as well as modifies the individuals stride length [101, 103]. Somatosensory feedback also plays a role in PC and bodily orientation by providing feedback with respect to contact surface, adjustment of gait and modification of stride frequency [101, 104, 105]. Thus, visual impairment and poor proprioception causes altered gait [106, 105].

The basal ganglia has several functions such as; sensory-motor agility [107]; the responsibility to regulate movement amplitude; to inhibit movements via direct and indirect pathways; [108] and to contribute to the regulation of postural alignment and axial motor control [109]. Consequently, because the basal ganglia is impaired in individuals with PD they suffer from a disturbance in sensory-motor functioning which leads to gait deficiencies [110]. Various gait abnormalities, such as reduced gait speed, shortened stride length and an increase in the time that both feet are on the floor (double-support time) have been reported in individuals with PD [111]. Furthermore, they also illustrate reduced or sometimes no arm swing, reduced trunk rotation as well as lower hip, knee and ankle movement amplitude [111]. All of these above mentioned gait abnormalities in individuals with PD can alter balance severely leading to an increased risk for falling.

2.3 Balance Training for Parkinson's Disease

Various studies have evaluated the effect of several balance training programs on PC in individuals with PD. Yet, when reviewing these articles, it must be noted that most of these balance-training programmes only addressed some dimensions of the PC system and had various outcome measures. This research study reviewed three different types of balance training programmes, namely Somatosensory/Proprioceptive training, Sensory integration training and lastly balance training. Moreover, this study only focussed on outcome measures that focussed on balance (static and dynamic), sensory integration and proprioception.

2.3.1 Somatosensory and Proprioceptive Training

Proprioceptive training is a broad term with various definitions and little consensus of what is actually meant by this specific mode of training. Aman et al. [14] proposed a definition that would help with the understanding of what constitutes proprioceptive training as well as understanding the efficiency of proprioceptive training. They suggested that, proprioceptive training should be defined as an intervention that focusses on somatosensory signals i.e. proprioception and haptic feedback, without receiving information from the other sensory systems such as the visual and vestibular system [14]. Furthermore, that such an intervention should focus on the improvement of proprioception and sensory-motor function [14].

For the purpose of this study the above mentioned definition was applied on individuals with PD specifically and included studies which executed an intervention focussed on improving proprioception with at least a pre- and post-intervention phase. Furthermore, studies had to contain at least one outcome measure indicating somatosensory function without any confusion from the visual or vestibular systems. Interestingly, two studies were found which looked at the effect of somatosensory stimulation training on individuals with PD [112, 113].

Haas et al. [112] investigated the effects of random Whole-Body Vibration (WBV) on leg proprioception in individuals with PD (Hoehn & Yahr: II-IV). Individuals ($56-70$ years) took medication as normal, while performing a pre-test, followed by a Treatment phase, and ended with a post-test. Experimental group ($n = 19$), received one session of five series of random WBV ($\bar{x}_{\text{frequency}}$: 6 Hz $\pm$ 1 Hz) taking 60 seconds each and the control group ($n = 9$), had a rest phase instead lasting 15 minutes. Joint position sense was tested at the knee joint by using a goniometer, where individuals had to perform five test series during pre- and post-testing, consisting of ten extension-flexion cycles each. Results show that there were no significant differences between the pre- and post-testing of the two groups as well as between the experimental and control group ($p > 0.05$). According to the researchers, short-term mechanical training stimuli did not improve proprioception in individuals with PD.

Ebersbach et al. [113], investigated the effect of WBV compared to conventional physiotherapy on balance and gait in individuals with PD. Participants ($62-84$ years) were randomly divided into either a WBV group ($n = 10$) or a conventional physiotherapy group ($n = 11$). Hoehn & Yahr scale (H&Y) was not used but individuals had to show imbalance by scoring at least 1 point on item 30 of Unified Parkinson's Disease Rating Scale (UPDRS). Both groups participated in 30 sessions consisting of 15 minute sessions a day for five times a week. The WBV group received training on an oscillating platform (25 Hz)

and the physiotherapy group did balance exercises including training on a tilt board. Individuals were tested on medication at baseline, at the end of treatment and also four weeks after treatment. The primary outcome measure was the Tinetti test, which could also indicate proprioceptive impairments. Researchers found that there was no convincing evidence for superior effectiveness of WBV compared to conventional physiotherapy. Tinetti balance score showed improvements in both groups ($p < 0.05$).

A study done by Xu and colleagues (2004) on proprioception and healthy elderly people, found that participating in regular Tai Chi showed better proprioception and stated that the large benefits of Tai Chi exercise on proprioception may result in the maintenance of balance control in older people. Up to date, only three studies have been done on the effect of Tai Chi on balance and mobility in individuals with PD [114, 51, 115]. Although these studies did not look at proprioception specifically, all of them found that Tai Chi is an appropriate exercise modality as well as an effective therapeutic modality to improve physical function and reduce balance impairments. These three studies will be discussed more in depth in the coming section, Balance Training.

2.3.2 Sensory Integration Training

Individuals with PD move slower and walk with smaller steps because they suffer from sensory-motor deficits, specifically integrating and making use of proprioceptive and sensory feedback [91]. With this sensory deficit identified, Sage and colleagues [16, 116, 117], developed a Sensory Attention Focused Exercise (SAFEx) training program which aims to improve awareness of sensory feedback, coordination, neurological function, and finally improved PD symptoms. Exercises were completed with eyes closed and cued to the sensory feedback from specific portions of each exercise, i.e. tandem walking for balance and coordination, side stretches down side of chair for sensory feedback etc. To the researcher's knowledge, there are only three studies who evaluated the SAFEx intervention on motor symptoms as well as static and dynamic balance in PD [16, 116, 117]. Recently, Lefaivre & Almeida [118] was the first study to determine whether the SAFEx intervention could improve PC and sensory integration in individuals with PD.

Sage et al. [16] aimed to have participants focus their attention on awareness of their body in space as well as on sensory feedback to evaluate the effect it has on symptoms and gait changes in individuals with mild to moderate PD. Individuals ($49 - 82$ years) were randomly divided into three groups, namely; SAFEx ($n = 18$), Aerobic ($n = 13$) and non-exercise control group ($n = 15$). Both groups were tested on medication, before the intervention started as well as after the intervention was complete. The two intervention groups exercised three times per week for $10 - 12$ weeks, while the control

group maintained their regular activity level for 12 weeks. Outcome measures included the UPDRS, TUG, and spatiotemporal aspects of self paced-gait. Results demonstrated that only the SAFEx group had improved PD symptoms after exercise ($p < 0.001$). Researchers concluded that sensory-based training was beneficial, leading to improvement in motor symptoms and functional outcome in individuals with PD.

In 2010, a similar study was published, looking at the effect of vision on motor symptoms during SAFEx in individuals with mild to moderate PD [116]. Individuals ($55 - 77$ years) were randomly divided into either a 12-week exercise program with (SAFEx; $n = 13$) or without (control; $n = 13$) increased attention focused on sensory feedback. Individuals were tested on medication, before and after the intervention as well as following a six-week non-exercise period. Outcome measures were similar to the previous study in 2009, assessing UPDRS, TUG, Grooved Pegboard (GP) and velocity and step length of self-paced gait. Both the SAFEx and control group significantly improved on the TUG ($p < 0.014$), GP ($p < 0.001$), and step length ($p < 0.046$), as well as maintained improvements after a six-week washout period ($p < 0.05$). Researchers once again found that only the SAFEx group significantly improved motor symptoms after the intervention ($p < 0.035$) and that these gains were maintained in the SAFEx group after the six-week retention period ($p < 0.05$), while motor symptoms significantly deteriorated in the control group ($p > 0.05$). This could suggest that motor symptoms could severely be impacted by increased awareness of sensory feedback.

Sage et al. [117] evaluated the effectiveness of four different exercise interventions on motor symptoms in individuals with PD. This was a quasi-experimental study where individuals ($54 - 79$ years) of any severity level, were randomly assigned to either aquatic ($n = 12$), aerobic ($n = 17$), strength ($n = 18$), SAFEx ($n = 24$) or a control group ($n = 18$). All groups were assessed before and immediately following intervention, as well as after a six-week non-exercise period. Only SAFEx group resulted in significant symptomatic improvement relative to non-exercising control participants ($p < 0.015$). The sensory ($p < 0.001$) and strength training ($p < 0.004$) groups also had significant UPDRS III reductions from pre- to post-intervention, however these benefits were not maintained after the non-exercise period ($p > 0.05$). Thus, researchers concluded that the SAFEx and strength training were the most effective strategies for individuals with PD.

Lastly, Lefaivre & Almeida [118] investigated the effects of the PD SAFEx on PC in PD. Participants (54-87 years) with mild to moderate PD (UPDRS III: 24.5 ± 10.2) participated in SAFEx program, three times a week for 12-weeks long. Postural control was tested on medication before (pre-test) and after (post-test) completing the intervention. Primary outcome measure was

the modified Clinical Test of Sensory Integration of Balance (mCTSIB) which allows assessment of specific sensory contributions to balance improvement during both eyes open and closed conditions, as well as on different surface areas. At post-test, participants significantly improved PC, specifically when eyes were closed ($p = 0.014$), whereas there was no difference in eyes open conditions. Researchers concluded that the SAFEx improves PC in the absence of vision because of an increased ability to utilise proprioceptive information.

2.3.3 Balance Training

Research shows that several interventions, such as general balance training, Tai Chi, challenging balance tasks as well as gait activities enhance postural stability and dynamic balance in individuals with PD [119, 114, 50, 120, 51, 115, 121, 122].

Smania et al. [50] evaluated the effects of balance training on postural instability in individuals with PD (H&Y: III-IV). Participants ($50-79$ years) were randomly assigned into either a control group, doing general physical exercises ($n = 31$) or a balance training group ($n = 33$). Individuals participated in 21 treatment sessions each 50 minutes in duration. Researchers evaluated Berg Balance Scale (BBS), Activities-specific Balance Confidence Scale (ABC), postural transfer test, number of falls and UPDRS. Results indicated significant improvement in performance in all of the outcome measures for the balance training group ($p < 0.05$), except for the UPDRS ($p = 0.063$). Contrarily, the control group showed no significant improvements in performance in any of the above mentioned outcome measures ($p > 0.05$). Researchers concluded that a balance training program could hold the potential to improve postural instability in individuals with PD.

A few studies have looked at the effect of Tai Chi on balance, mobility and postural stability in individuals with PD specifically [114, 51, 115]. Li et al. [119] were the first researchers who did a pilot study suggesting that Tai Chi is an appropriate physical activity for individuals with PD. Researchers concluded that Tai Chi could hold the potential to be useful as a therapeutic exercise modality, but that further investigation in warranted.

Hackney et al. [114], looked at the effect of 20 sessions, 60 minutes each, of Tai Chi on balance, gait and mobility in individuals with PD (Modified H&Y: $1.5-3$; $52-73$ years). Thirty-two people with PD were randomly assigned to either a Tai Chi group ($n = 17$) or a control group ($n = 15$). The control group received no training and all participants were tested on medication, before and after the intervention. Outcome measures consisted of the BBS, UPDRS, TUG, tandem stance test, six-minute walk, and backward walking. Results indicated that there was a significant group difference for BBS ($p = 0.001$)

after the intervention. Furthermore, the Tai Chi group also improved on the UPDRS part III, tandem stance, TUG, and the six-minute walk ($p < 0.05$), while the control group showed little change on these measures ($p > 0.05$). Researchers established that Tai Chi could be an effective form of exercise to improve gait, balance and functional mobility in individuals with PD.

Li et al. [51] conducted a study to examine the effect of a Tai Chi program on PC in patients with idiopathic PD (H&Y: I-IV). Individuals ($40-85$ years) were randomly divided into three groups namely, Tai Chi ($n = 65$), resistance training ($n = 65$), or stretching ($n = 65$) and all individuals participated in 60-minute exercise sessions twice weekly for 24 weeks. Primary outcome measures included limits-of-stability, and secondary outcome measure were TUG, number of falls and motor scores on UPDRS. The Tai Chi group showed significant improvement in limits-of-stability test compared to the resistance training group ($p = 0.01$) as well as the stretching group ($p = 0.001$). Furthermore, results indicated that the Tai Chi group performed significantly better than the stretching group ($p < 0.05$) in all three secondary outcome measure, but not compared to the resistance training group ($p > 0.05$). Researchers concluded that Tai Chi training does not only improve balance impairments but also has the potential to reduce falls and improve functional capacity.

Lastly, Gao et al. [115] examined the effects on Tai Chi on balance, functional mobility and fall risk in individuals with PD (H&Y: I-V). Participants ($60-77$ years) were randomly divided into two groups, namely Tai Chi ($n = 37$) or control group ($n = 39$), and were tested on medication, before and after the intervention. Individuals underwent further assessment after a six-month retention period during a follow-up session. The experimental group received 60 minutes of Tai Chi, three times a week lasting 12 weeks. Outcome measures included BBS, UPDRS part III, TUG and occurrences of falls. Results indicated that BBS improved more in the Tai Chi compared to the control ($p < 0.05$). Contrarily, there was no group difference for UPDRS part III scores and TUG times ($p > 0.05$). After the six-month retention period there was a significant group difference for fall occurrence ($p < 0.05$), since less individuals experienced a fall in the Tai Chi group (8/37), whereas more individuals fell in the control group (19/39). Researchers concluded that Tai Chi exercise could improve balance and decrease the fall risks in Parkinsonian individuals.

A study was done to look at the effect of a Nintendo Wii Fit game with balance board intervention on balance and functional ability in individuals with PD ($n = 10$; $48 - 80$ years) compared to healthy individuals ($n = 8$; $49-81$ years) [120]. Researchers looked at various outcome measures, namely Sit-to-Stand test (STST), TUG, Performance Oriented Mobility Assessment (POMA), Community Balance and Mobility assessment (CBM), 10 m walk test, ABC, unipodal stance duration, and a force platform. Training program

was six weeks long and individuals were tested on medication, before, three weeks into the program, and after the intervention period. Results revealed that after the intervention the PD participants improved all the above mentioned dynamic balance outcome measures ($p < 0.05$), whereas the healthy control group only improved in the TUG, STST and CBM ($p < 0.05$). Thus, researchers concluded that this training program could be effective in improving dynamic balance abilities in individuals with PD.

A recent study looked at the effect of an eight-week multi-dimensional balance training programme in individuals with PD [84]. Their objective was to examine the short- and long-term effects on balance, balance confidence and gait performance in people with PD (H&Y: II-III) when participating in an eight week multi-dimensional indoor and outdoor exercise programme. Individuals ($50-71$ years) were divided into either an experimental group ($n = 41$), who participated in indoor and outdoor balance training, or a control group ($n = 43$), participating in upper limb exercises. Parkinson's disease participants were tested on medication, before and after the intervention, for short term effects, as well as six and twelve months after the intervention to look at long-term effects. They had several outcome measures such as the Balance Evaluation Systems Test (BESTest) total and subsection scores, gait speed, dual-task TUG and ABC score. During post-testing the experimental group showed significant improvements in all outcome measures ($p < 0.05$), except the ABC. After six months the experimental group still showed the same improvements as after the intervention ($p < 0.05$), but after the 12 month testing the participants only had significant gains in the BESTest total and subsection scores and dual-task TUG time ($p < 0.05$). The researchers concluded that a multi-dimensional balance training programme may have short term and long term effect to enhance balance and dual-task gait performance in individuals with PD.

Furthermore, another recent study was done looking at the influence of a 10-week highly challenging balance-training program on individuals with PD [121]. Individuals ($67 - 78$ years) were allocated to either the experimental group ($n = 47$), who received the balance training regimen, or control group ($n = 44$), receiving usual care for elderly with PD (H&Y: II-III). All participants were tested on medication at the same time of the day for pre- and post-test. The main outcome measures of this study was the mini-BESTest, normal as well as dual-task gait velocity and concerns about falling. After the intervention the training group had significantly improved their mini-BESTest as well as gait velocity and step length during normal walking ($p < 0.05$), while the control group showed no statistically significant improvements. The highly challenging balance program had significant short-term effects, benefiting balance and gait abilities in individuals with PD when compared to usual PD care.

Up to date, only a few studies looked at the effect of somatosensory stimulation on dynamic balance [123, 124] and motor symptoms [125] in individuals with PD. Above mentioned studies used WBV, with frequencies lower than 10 Hz during 5 vibration sets of 1 minute each. Dynamic balance was tested with the TUG and motor symptoms with UPDRS, before and after stimulation, the one while paticipants ($56 - 78$ years) were off medication [123], and the other two while participants were on medication ($57 - 63$ years; H&Y: II-IV) [125] ($57 - 79$ years) [124]. Both Arias et al. [123] and Chouza et al. [124] found no improvement in TUG after the stimulation ($p > 0.05$), whereas Haas et al. [125] concluded that WBV has beneficial effects on PD motor symptoms. Nevertheless, there is insufficient evidence to support the use of WBV intervention in PD individuals and more research is needed on effective somatosensory training study designs [126].

2.4 Problem Statement

There is a growing body of evidence that exercise is a successful method for improving PD related signs and symptoms, in particular balance improvements. Recent findings recommend that intensive and challenging exercises induce neuroplasticity, suggesting that exercise is becoming essential in PD treatment [127]. Sehm and colleagues [128], recently investigated the effect of balance training on structural brain plasticity in PD and revealed that the human brain has the capacity to undergo learning-related structural plasticity. Furthermore, these researchers found that structural brain plasticity correlated directly with performance improvements over the whole time course of learning [128].

It is important to research effective practice design methods, such as somatosensory training, because only a few clinical trials have investigated balance exercises emphasising specific training characteristics [56]. Research is vague on the details of practice designs needed for successful motor task outcomes [42], thus investigating this further will result in the improvement of QoL as well as a more independent and sustainable lifestyle for individuals suffering from PD.

For the purpose of this study independent-living was defined as individuals who do not live in an institutional setting, but as those who have the ability to live a freely chosen lifestyle in the community. Independent living focuses on the degree of control when executing activities, not the individuals' physical capabilities. Brisenden [5] believed that an independent lifestyle could be applied to severely disabled individuals as long as they take control of their life and choose how that life should be led. The amount of independence achieved should not be determined by the extent of the individuals' disability. The H&Y

scale is based on an individual's disability resulting from motor impairment as well as balance dysfunction, and is the most frequently used assessment tool for PD [129]. However, this scale does not provide information regarding the individuals motor features and non-motor manifestations [7]. Thus, cut-off points have been proposed to classify PD individuals as mild, moderate or severe based on the Movement Disorder Society-Unified Parkinson's Disease Rating Scale (MDS-UPDRS), as it entails a more detailed assessment taking motor features into consideration [7]. Research suggests that the motor section of the MDS-UPDRS (Part III), measures motor impairment, disease severity, and disability [130, 129]. Thus, participants were automatically included in the study if they had a severity level of I-III on the H&Y scale. However, if they scored IV on the H&Y scale, their MDS-UPDRS part III score had to be less than 59 [7].

Postural instability is a disabling feature of PD and cannot easily be corrected by dopaminergic medications [50]. This is supported by Jöbges and colleagues [131] who stated that dopaminergic medication fails to improve balance in PD individuals, which leads to compensation for these postural instabilities. Non-pharmacological interventions addressing postural instability are important and research is wanted. Postural instability enhances the risk of falling, which is associated with later injuries and further disability [128]. Exercise and rehabilitation programs could modify disease progression and additionally improve motor symptoms in individuals with PD [132].

To date there are only two investigations which have researched the influence of somatosensory-based training focussed on improving proprioception in individuals with PD, both of which entailed WBV therapy. Sample sizes in these studies ranged from 22 to 28 participants, between the ages of 56 and 84 years old and included individuals with mild to severe PD (H&Y: II-IV). All of the investigations assessed participants on their regular medication, however none reported the regular medication or when it was taken. The longest interventions took place five days per week over six weeks and were 30 minutes long, whereas the shortest intervention lasted five sessions on one day for 60 seconds each.

As a result, there is still uncertainty on this topic and more research is warranted. Individuals with PD need lifelong management, which can be very costly. Many individuals feel more comfortable in their own homes, may live far distances from a rehabilitation centre and might be unwilling or unable to travel these far distances. Thus, developing ways that are more feasible for individuals to engage in exercise programs, independently, will lead to improvement of QoL as well as executing activities of daily living.

2.4.1 Primary Aim

The primary aim of this investigation was to establish if an eight-week somatosensory training program (SSTP) would influence PC in individuals with mild to moderate PD.

To answer this question a time-series experimental study design was used of which the first eight weeks was a Baseline phase and the next eight weeks, participants received either a placebo treatment or the somatosensory intervention, referred to as the Treatment phase. The aims and objectives for the SSTP can be found in Appendix A and the design of the SSTP in Appendix B

2.4.2 Objectives

The following objectives were set out to assess the primary outcome measures at baseline as well as before and after the intervention(s) to answer the main research aim:

Article 1

- To assess JPS with the Active Movement Extent Discrimination Apparatus (AMEDA).
- To determine sensory integration and reweighting with the mCTSIB.
- To evaluate QoL via the Parkinson's Disease Quality of Life Questionnaire Summary Index (PDQ-39 SI; Appendix C).

Article 2

- To quantify mobility and functional balance with the TUG.
- To monitor fear of falling with the Fall Efficacy Scale-International (FES-I; Appendix D).
- To assess motor functionality (part III) and overall severity of PD (total score) with the MDS-UPDRS.

Article 3

- To assess effect of haptic feedback on PS with the Instrumented Sway (ISway).
- To evaluate balance confidence with the ABC questionnaire (Appendix E).
- To evaluate motor experiences of daily living (part II) with the MDS-UPDRS.

Descriptive Outcome Measures for all Articles

- Obtain Informed Consent (Appendix F), Personal Information (Appendix G) and Health Status (Appendix H) before commencing the SSTP.
- Describe participants' PD severity level with H&Y scale as well as MDS-UPDRS part III.
- Assess mild cognitive impairment with the Montreal Cognitive Assessment (MoCA; Appendix I).
- Describe EXP participants' intrinsic motivation levels after completion of SSTP with the Intrinsic Motivation Inventory (IMI; Appendix 12 J).

A list of medication and participant affected side can be viewed in Appendix K. The study was approved by the Institutional Research Ethics Committee (HS1041/201) and all tests were conducted with professionalism and in accordance with the *Declaration of Helsinki* (Appendix L). Furthermore, Article two was submitted to *Gait & Posture* as an original article for publication (Appendix M).

2.4.3 Variables

The Independent, Dependent, Categorical and Control Variables used in this study are listed in Table 2.2.

Table 2.2: Summary of research variables.

Independent Variable	Dependent Variable	Categorical Variable	Control Variable
Eight-week SSTP	Joint position sense	Age	Medication
	Postural sway	Weight	Activity levels
	Mobility and functional balance	Height	Cognitive impairment
	Quality of life	Body Mass Index	
	Fear of falling	Gender	
	Balance confidence	Severity level	

Abbreviations: SSTP: Somatosensory Training Program.

2.5 Conclusion

As mentioned earlier in the introduction, individuals with PD suffer from dysfunctional basal ganglia, which has been suggested to play an important role in the integration of proprioceptive feedback during movement [133]. Thus, we can draw the conclusion that individuals with PD have a poor ability to integrate and utilise sensory feedback, especially proprioception [91].

Only a few clinical trials have investigated somatosensory exercises emphasising specific training characteristics and research is unclear on the details of practice designs needed for successful motor task outcomes. Furthermore, a number of studies have set out to determine the best type of training to improve dynamic balance and limit possible falls in individuals with PD. To the researcher's knowledge, no studies have been done investigating the effect of a SSTP on dynamic balance outcome measures in individuals with PD, implicating that research is wanted. As a result, it is important to research effective practice design methods, such as somatosensory training, which will possibly lead to correct motor program execution through improved proprioceptive feedback and sensory integration. Thus, it is very important to uncover the underlying neurophysiological mechanism of sensory integration as well as find effective ways on how to improve proprioception in individuals with PD, so that they can integrate and utilise proprioceptive feedback correctly.

In the next three Chapters, the investigation in whether an eight-week SSTP could influence PC in individuals with PD is presented. Research is presented in the form of three articles; Article 1 (Chapter 3) focusses on JPS, sensory integration and QoL; Article 2 (Chapter 4) on mobility and functional balance, fall risk and motor symptoms; and Article 3 (Chapter 5) focusses on PS with and without haptic feedback as well as balance confidence and motor experiences of daily living in individuals with PD.

Chapter 3

Article 1

Somatosensory training improves sensory integration and quality of life in individuals with mild to moderate Parkinson's disease

3.1 Abstract

Introduction: Parkinson's disease (PD) presents proprioceptive processing and integration deficits, which cause postural control (PC) deterioration. However, applying light touch improves postural sway (PS) in individuals with PD. The aim was to determine whether an eight-week somatosensory training programme (SSTP) would influence joint position sense (JPS), sensory integration and Quality of Life (QoL) in individuals with PD.

Methods: Thirty-seven individuals with idiopathic PD (67 ± 9 years; H&Y: 2 ± 1) were divided into two groups: somatosensory training (EXP; n = 24) and placebo group (PBO; n = 13). Joint position sense, sensory integration (mCTSIB) and QoL were assessed at baseline, pre- and post-intervention. For the mCTSIB, the Instrumented Sway tri-axial accelerometer was used to assess Jerkiness (JERK), Centroidal Frequency (CF) and Root Mean Square (RMS) during 4 conditions i.e. eyes open (EO), eyes closed (EC), both off and on a foam pad (+F). Joint position sense was tested by means of the Active Movement Extent Discrimination Apparatus (AMEDA) and QoL with the Parkinson's Disease Quality of Life Questionnaire Summary Index (PDQ-39 SI).

Results: A treatment effect was found for EC+F ($p = 0.0002$) and a strong tendency for a treatment effect for PDQ-39 SI ($p = 0.06$). The EXP group improved in JPS ($p = 0.02$) and PDQ-39 SI ($p = 0.03$) after the eight weeks. Furthermore, the EXP group showed less EC+F JERK compared to PBO group after the intervention ($p = 0.002$).

Conclusions: The study findings provide evidence that SSTP might improve JPS and sensory integration in individuals with PD, which may contribute to improve PC.

Keywords: Parkinson's disease; Somatosensory training; Sensory integration.

3.2 Introduction

Parkinson's disease (PD) affects the motor, sensory as well as cognitive systems, which may contribute to balance impairment and frequent falling [134]. Postural control (PC), more commonly known as balance, is a complex skill based on the interaction of dynamic sensory-motor processes which allows one to maintain an unsteady equilibrium while the muscles work against gravity [27].

Sensory-motor interaction refers to the process whereby the central nervous system integrates sensory input with motor programme execution [27]. Sensory information from the somatosensory, vestibular and visual systems are integrated, and the importance placed on each of these sensory inputs relies on movement goals and context [27, 135]. Investigating the interaction of the sensory systems could be used to identify whether an individual has normal sensory organisation or sensory selection problems, such as being highly visual- and/or somatosensory-dependent to maintain their balance [135].

Impairment of the basal ganglia in PD disrupts sensory-motor integration leading to individuals having impaired proprioception [79]. The somatosensory system includes the processing of tactile, proprioceptive as well as nociceptive information [26]. More specifically, proprioception refers to the sensations of consciousness of posture and body movements, which enables the body to orient itself in space without visual clues [136]. Vaugoyeau et al. [137] also reported that individuals with PD typically include deficits in the processing and integration of proprioception. More recently Bekkers et al. [138] stated that proprioceptive deficits negatively affect PC but that the precise contribution to postural instability in PD is unclear. Inaccurate proprioceptive feedback may result in an overestimation of movement amplitude [139] as well as increased reliance on visual feedback for PC [140].

Postural orientation is the purposeful alignment of the trunk and head in relation to gravity, support surfaces, the visual field and internal framework of the person involved [27]. According to Vaugoyeau & Azulay [141], Parkinsonian individuals have impaired control of body orientation, which could be explained partly by a deficit of proprioceptive information. Elangovan et al. [142] stated that, proprioceptive acuity is indicated by the difference between two positions when repeated matching of a given joint position with the same or opposite limb is tested. Joint position sense (JPS) is described as the ability to perceive the position of the joint (e.g. ankle) in the absence of vision. The question remains however if proprioception i.e. JPS and sensory integration processing can be altered through somatosensory-based exercises which stimulates the peripheral proprioceptive and cutaneous systems during movements.

To date only two studies have implemented interventions focussing on improving proprioception in individuals with PD. Both studies had at least one outcome measure indicating somatosensory function, without any input from the visual or vestibular systems. [112, 113]. Haas et al. [112] investigated the effects of Whole-Body Vibration (WBV) on leg proprioception in individuals with PD. Knee JPS was assessed using a goniometer, where individuals had to perform five test series during pre- and post-testing, consisting of ten extension-flexion cycles each. However, no significant differences were found between the two groups or over the intervention in JPS. Ebersbach et al. [113] compared WBV to conventional physiotherapy training on balance and gait ($62 - 84$ years). The primary outcome measure was the Tinetti test, which may suggest proprioceptive impairments. Researchers found that there was no convincing evidence for superior effectiveness of WBV compared to conventional physiotherapy.

Balance exercise targeting PD specific characteristics, have sparsely been tested in clinical trials, mostly because of the uncertainty of the feasibility and safety of these training conditions [56]. Lefaivre & Almeida [118], were the first researchers to look at the effect of a Sensory Attention Focussed Exercise (SAFEx) training programme on balance and sensory integration in individuals with PD. Researchers found that the SAFEx programme improved the ability to utilise proprioceptive information, leading to improved PC in the absence of vision. Nevertheless, research is vague on the details of practice designs needed for successful motor task outcomes [42] and only a few clinical trials have investigated balance exercises emphasising specific training characteristics [56]. Therefore, it is important to research exercise interventions, such as somatosensory training, which may possibly lead to accurate movement execution through improved proprioceptive feedback and sensory integration.

The current investigation set out to assess whether an eight-week somatosensory training programme (SSTP) will influence JPS and sensory integration processing in individuals with mild to moderate PD. A successful SSTP may improve proprioceptive feedback, which could lead to better posture and balance in individuals with PD, as well as give insight as to whether proprioceptive deficits in individuals with PD could be addressed directly, instead of training other compensatory strategies.

3.3 Methods

3.3.1 Participants

Fifty-five individuals with PD were recruited to take part in the study via local media such as newspaper articles and support groups. After the recruit-

ment phase, only 44 individuals met the study inclusion criteria. Men and women between the ages of $50-85$ years, who have been diagnosed with mild to moderate idiopathic PD by their neurologist, were allowed to take part in the study. Thus, participants were automatically included in the study if they had a severity level of I-III on the Hoehn and Yahr scale (H&Y) [6]. However, if they scored IV on the H&Y scale, their Movement Disorder Society-Unified Parkinson's Disease Rating Scale (MDS-UPDRS) part III score had to be less than 59 [7]. In addition, participants were included if they lived an independent-living lifestyle, in other words those who do not live in an institutional setting, but who have the ability to live a freely chosen lifestyle in their community. Individuals were excluded if they had other neurological conditions other than PD (e.g. Diabetes, stroke), moderate to severe cognitive impairment (<17 on the Montreal Cognitive Assessment (MoCA) [143]), any un-correctable visual and vestibular problems or if they did not adhere to the intervention. Participants had to attend at least 70% of the exercise sessions, and were not permitted to miss more than two consecutive sessions. Seven individuals were excluded after the intervention had begun; three participants did not attend 70% of the SSTP, two participants underwent adverse falls during the Treatment phase (outside of SSTP sessions), one participant received medication changes, and one participant withdrew due to health problems.

3.3.2 Study Design and Sampling

This was a time-series experimental study with a sample of convenience which included an eight-week Baseline phase (baseline to pre-intervention) followed by an eight-week Treatment phase (pre- to post-intervention). Participants were divided into two groups namely a placebo group (PBO) and an experimental group (EXP). The PBO wore a wristband during the Treatment phase and were blinded to the true purpose of the wristband, and the EXP participated in an eight-week SSTP. Both groups were tested three times i.e. baseline, pre-intervention and post-intervention. The total testing period for both groups was 16-weeks. The study was approved by the Institutional Research Ethics Committee (HS1041/201). Participants completed informed consent forms prior to participation. All tests were conducted with professionalism and in accordance with the *Declaration of Helsinki*.

3.3.3 Intervention

Participants either received three SSTP sessions per week, each progressively increasing in complexity and difficulty, or had to wear a placebo wristband over an eight-week period after the Baseline phase. All SSTP sessions lasted $30-60$ minutes, of which $15-40$ minutes (dependent on week) were allocated to somatosensory exercises along with a standardised 10 minute warm-up and 5

minute cool-down consisting of light aerobic activities, stretching and relaxing techniques.

3.3.4 Baseline Phase

Each individual acted as their own control for the first eight weeks of the study regardless of the group that they were in. This was done to measure the baseline status of each participant before the intervention started. Physical activities participated in during this phase were taken note of and were the only physical activities the individuals were allowed to continue doing during the Treatment phase. Thus, no changes in their level of activity participation occurred after this phase.

3.3.5 Treatment Phase

3.3.5.1 Somatosensory Training Group

The SSTP included balance exercises that focused on somatosensory input i.e. proprioception and haptic feedback, and receiving none or limited information from the other sensory systems such as the visual and vestibular system [14]. Progressions were adapted from Janda's sensory-motor training principles [97] as well as according to guidelines given by Conradsson et al. [121]. Sessions were led by two clinical Exercise Therapists (biokineticists) and individuals were given short rest periods within the exercise sessions. The same warm-up and cool-down activities were used throughout the eight weeks. This created familiarity with the emphasis on stretching, and very light aerobic activities i.e. kicking a ball.

3.3.5.2 Placebo Group

The PBO group was asked to wear a wristband daily over eight weeks. Individuals were told that when they notice the wristband that they should stand upright and focus on their balance, and that the purpose of the wristband is to provide reinforcement of behavioural feedback. The PBO group also received a balance training DVD after completing the study. This DVD contained exercises similar to the EXP group.

3.3.6 Measurements and Procedures

Assessments took place in participants' homes or at the Movement Laboratory (Stellenbosch University). The testing took place at the same venue, time of day and in the same sequence by the same assessor, while participants were on medication. Participants were told to take their medication as per usual.

3.3.7 Primary Outcome Measures

Joint position sense was assessed with the Active Movement Extent Discrimination Apparatus (AMEDA) [144]. Ankle JPS was tested barefoot and full weight bearing, with participants' dominant leg on a square footplate. The footplate tilted along its central axis by actively moving their foot into ankle plantar flexion while standing upright. Participants then return the plate to a horizontal stop position at the same steady pace to make a judgement as to the degree of ankle plantar flexion. Movements were stopped at one of five fixed angles namely, 10°, 11°, 12°, 13° and 14° of plantar flexion from horizontal, which were taught to each participant as stop one to five respectively [144]. Before the AMEDA testing started participants were standardised with a warm-up activity, in which the participants were shown all five-stop positions corresponding to the different ankle plantar flexion angles, in sequence one to five, three times uninterruptedly. Each participant had to stand on the AMEDA, having to differentiate between the five angles during 50 randomly sequenced repetitions, thus each angle repeated 10 times.

Sensory integration as well as participants' overall postural sway (PS) was measured by means of the modified Clinical Test of Sensory Integration and Balance (mCTSIB). The Instrumented Sway or ISway (APDM, Inc.; Mobility labTM, Portland, USA) is a body worn tri-axial accelerometer with gyro meter to offer an objective and practical measure of PS. Overall Jerkiness (JERK), Centroidal Frequency (CF) and Root Mean Square (RMS) were assessed. Postural sway was measured for 30 seconds, during four different sensory tasks i.e. (1) standing with eyes open on a firm surface (EO); (2) standing with eyes closed on a firm surface (EC); (3) standing with eyes open on foam (EO+F); and (4) standing with eyes closed on foam (EC+F). Subjects were instructed to stand with their arms crossed and hands over their shoulders, while in a semi-tandem stance position (feet 15cm apart). Mancini (2012) found the ISway to be both experimental and clinically valid ($r = 0.50 - 0.63$), reliable (ICC= $0.55 - 0.86$), as well as a practical and objective PC test that is sensitive to mild neurological diseases.

3.3.8 Secondary Outcome Measures

Health Status and Level of Activity and Participation: Parkinson's Disease Quality of Life Questionnaire Summary Index (PDQ-39 SI) [145], H&Y stage [6], MDS-UPDRS part III [7], MoCA [143], Intrinsic Motivation Inventory (IMI) [146].

3.3.9 Statistical Analysis

Statistical analysis was performed using STATISTICA version 12 (StatSoft, Inc., Tulsa, OK, USA) software for Windows. All outcome variables were tested for differences at baseline between the two groups. Descriptive statistics are reported as mean, standard deviation (± SD), Standard Error of Mean (SEM), 95% Confidence Intervals (CI) and range unless otherwise specified. The comparison between the EXP and PBO groups' JPS, sensory integration and QoL are analysed with a mixed model repeated measures ANOVA's and a Fisher Exact LSD post-hoc analysis over the two eight-week phases. After assessing normal probability plots, non-normally distributed data was log transformed ($^{\text{Log}}$). Level of significance was set at $\alpha = 0.05$. Cohen's effect sizes (d) were used to determine the practical differences between the groups at each assessment. Abbreviations used for defining effect sizes included the following: $^{\text{N}}$: Negligible effect size; $^{\text{S}}$: Small effect size; $^{\text{M}}$: Medium effect size; $^{\text{L}}$: Large effect size; $^{\text{VL}}$: Very large effect size [147]; d_{base}: baseline, d_{pre}: pre-intervention and d_{post}: post-intervention values.

3.4 Results

Thirty-seven participants completed the study. Thirteen received the PBO and 24 the SSTP (EXP) intervention. On average the EXP attended 21 ± 2 sessions.

3.4.1 Baseline Characteristics

Participants' demographic data are summarised in Table 3.1 and no differences were found between the groups ($p > 0.05$). Table 3.2 summarises the JPS, parameters overall JERK, CF and RMS as well as PDQ-39 SI. There were no group differences for JPS ($p = 0.11$), or any of the JERK, RMS or CF parameters during condition 1 and condition 4 ($p > 0.05$), with an exception of a 61% group difference during JERK condition 3 ($p = 0.004$) as well as a 15% and 21% group difference for CF condition 2 ($p = 0.03$) and condition 3 ($p = 0.02$), respectively. Furthermore, there were no significant changes within groups after the Baseline phase for JPS or PS parameters, but a 22% difference in PBO for PDQ-39 SI ($p = 0.02$). Lastly, the EXP participants showed very good subjective experiences with regards to the SSTP (IMI; Figure 3.1).

3.4.2 Primary Outcome Measures

3.4.2.1 Joint Position Sense

No significant treatment effect was found in absolute JPS error (Table 3.2). There were no differences between the groups for pre- or post-intervention

Table 3.1: Demographic characteristics of participants in PBO and EXP groups (mean ± SD).

Variable	PBO (n=13)	Range	EXP (n=24)	Range	p value
Age (years)	71 ± 10	49-83	65 ± 8	50-79	0.09
Weight (kg)	78.4 ± 17.2	47.0-98.3	80.0 ± 17.1	52.0-126.7	0.79
Height (m)	1.8 ± 0.1	1.5-1.9	1.7 ± 0.1	1.5-1.8	0.80
BMI (kg/m^2)	27.5 ± 5.3	19.7-36.7	28.6 ± 6.0	21.1-43.6	0.59
H&Y	2 ± 1	1-4	2 ± 1	2-3	0.12
MDS-UPDRS III	22.5 ± 11.9	7.0-45.0	31.3 ± 14.4	6.0-53.0	0.06
MoCA	24.7 ± 3.0	19.0-30.0	23.9 ± 2.8	19.0-30.0	0.43

Abbreviations: BMI: Body Mass Index; EXP: Experimental group; H&Y: Hoehn and Yahr scale; MDS-UPDRS: Movement Disorder Society-Unified Parkinson's Disease Rating Scale; MoCA: Montreal Cognitive Assessment; PBO: Placebo group.

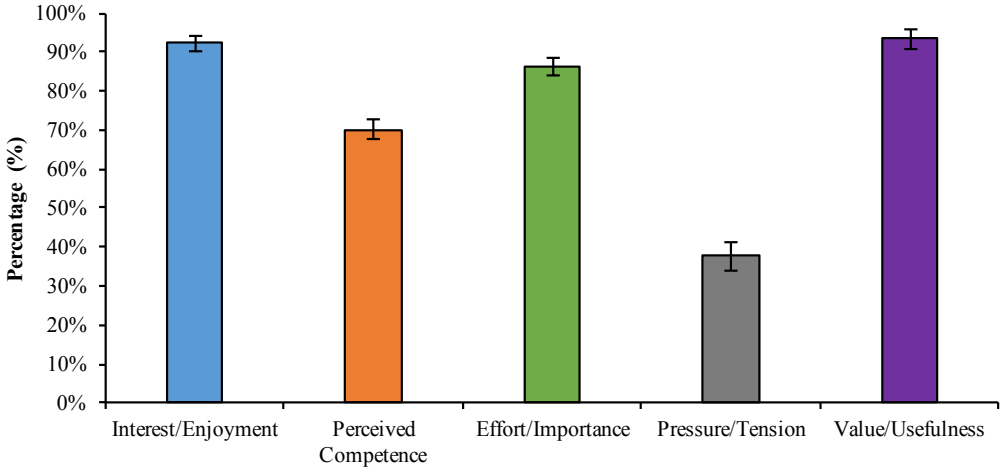


Figure 3.1: The Intrinsic Motivation Inventory results of EXP after Treatment phase (mean and SEM).

($p > 0.05$; $d_{pre} = 0.11^{N}$; $d_{post} = 0.23^{S}$). There was a 12% and 11% decrease in error over the Treatment phase in the EXP ($p = 0.02$; $d = 0.47^{M}$) and PBO ($p = 0.08$; $d = 0.43^{M}$), respectively.

3.4.2.2 Sensory Integration

Jerkiness

No group differences were found for condition 1 and 2 ($p > 0.05$). For condition 3, the EXP had 55% and 62% less jerkiness during pre- ($p < 0.01$; $d = 0.85^{L}$) and post-intervention ($p < 0.01$; $d = 0.88^{L}$), respectively. There

was a significant treatment effect for condition 4 (Table 3.2) as well as a group difference after the Treatment phase ($p < 0.0005$; $d = 1.32^{VL}$), with the EXP group showing 73% less jerkiness than the PBO group (Table 3.2). After the Treatment phase the EXP presented 69% improvement ($p = 0.002$; $d = 0.38^{S}$) in condition 4 (Figure 3.2).

During condition 1 the EXP group showed less jerkiness compared to condition 2 ($p < 0.01$; $d_{pre} = 0.43^{M}$; $d_{post} = 0.71^{M}$), condition 4 ($p < 0.01$; $d_{pre} = 0.53^{M}$; $d_{post} = 1.00^{L}$) but not condition 3 ($p > 0.05$; $d_{pre} = 0.04^{N}$; $d_{post} = 0.12^{N}$). Results from condition 2 and 4 in EXP indicated less jerkiness during condition 2 ($p < 0.01$; $d_{pre} = 0.42^{M}$; $d_{post} = 0.62^{M}$). The EXP group also presented less JERK during condition 3 in comparison to condition 2 ($p < 0.01$; $d_{pre} = 0.42^{M}$; $d_{post} = 0.62^{M}$) and condition 4 ($p < 0.01$; $d_{pre} = 0.53^{M}$; $d_{post} = 0.98^{L}$). The PBO followed a similar pattern (Figure 3.3); JERK was lower during condition 1 compared to condition 2 ($p = 0.01$; $d_{pre} = 1.23^{VL}$; $d_{post} = 1.99^{H}$), condition 4 ($p = 0.01$; $d_{pre} = 1.33^{VL}$; $d_{post} = 1.68^{H}$) and condition 3 ($p < 0.01$; $d_{pre} = 0.78^{L}$; $d_{post} = 0.92^{L}$). More JERK was found in PBO during condition 4 compared to condition 2 ($p < 0.01$; $d_{pre} = 1.07^{L}$; $d_{post} = 1.48^{H}$). Comparing the PBO overall JERK during condition 3 with condition 2 and 4, shows that individuals swayed with more jerkiness during condition 2 ($p < 0.05$; $d_{pre} = 0.62^{M}$; $d_{post} = 0.40^{M}$) and condition 4 ($p < 0.01$; $d_{pre} = 1.22^{VL}$; $d_{post} = 1.54^{H}$) (Table 3.2).

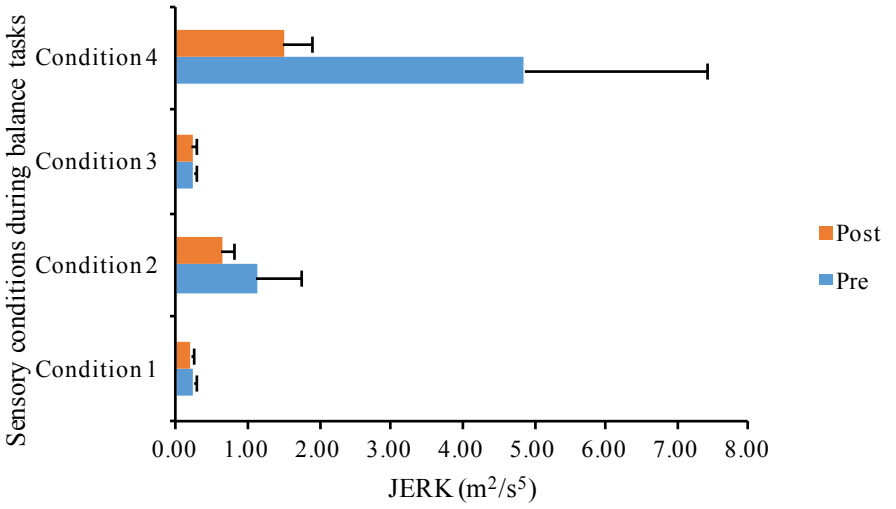


Figure 3.2: The overall jerkiness during pre- and post-intervention in EXP group (mean and SEM).

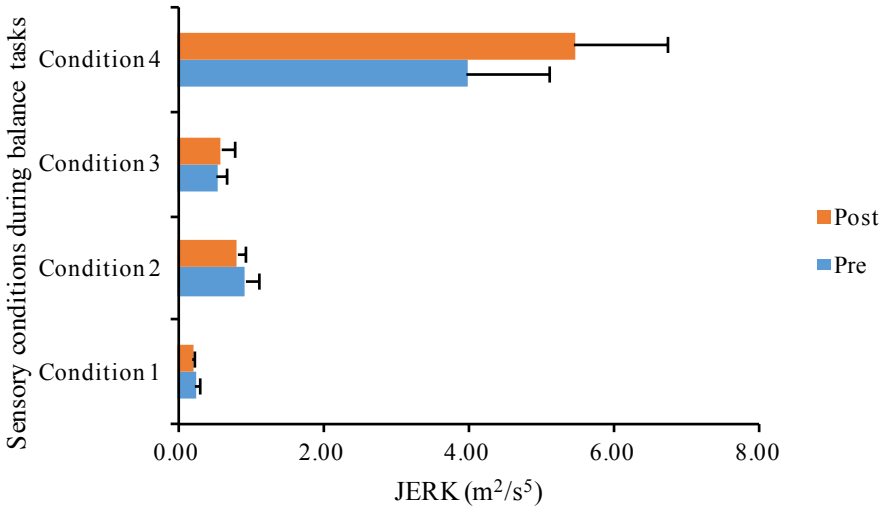


Figure 3.3: The overall jerkiness during pre- and post-intervention in PBO group (mean and SEM).

Centroidal Frequency

There was a group difference after the intervention for condition 1 ($p = 0.02$; $d = 0.98^{L}$), and 4 ($p = 0.002$; $d = 1.26^{VL}$); indicating less frequency of sway for the EXP group of 19% and 29%, respectively. Condition 3 showed similar results to that seen in JERK, with the EXP having 20% and 28% less sway during the pre- ($p < 0.001$; $d = 0.70^{M}$) and post-intervention ($p < 0.001$; $d = 1.11^{VL}$). There was a 14% improvement during the first condition for the EXP group from pre- to post-intervention ($p = 0.008$; $d = 0.62^{M}$). The PBO showed a 21% worsening in frequency of sway during condition 4 from pre- to post-intervention ($p = 0.01$; $d = 0.68^{M}$) (Table 3.2).

There was a difference in pre-intervention between condition 1 compared to condition 3 ($p < 0.01$; $d_{pre} = 1.21^{VL}$) and 4 ($p < 0.01$; $d_{pre} = 0.68^{M}$), showing a higher frequency of sway during condition 1 in EXP. The same pattern was found when comparing condition 2 with condition 3 ($p < 0.01$; $d_{pre} = 0.70^{M}$; $d_{post} = 0.66^{M}$) and 4 ($p < 0.05$; $d_{pre} = 0.45^{M}$; $d_{post} = 0.48^{M}$), with condition 2 showing more frequency of sway. The PBO group showed no significant results when comparing conditions ($p > 0.05$).

Root Mean Square

The same pattern was found in RMS as in JERK for the EXP group when looking at the effect of different conditions on each other. With exception that

there was a difference between condition 1 and 3, with condition 1 showing less RMS than condition 3 ($p < 0.01$; $d_{pre} = 0.37^{S}$; $d_{post} = 0.46^{M}$). Furthermore, there was no difference between condition 2 and 3 in the post-intervention ($p > 0.05$; $d = 0.15^{S}$). Lastly, the EXP group also showed an improvement in condition 4 after the intervention of 26% ($p = 0.01$; $d = 0.39^{S}$). The same case was found in the PBO group, with the only difference being that there was no significant difference when comparing condition 2 and 3 during the pre-intervention ($p > 0.05$; $d = 0.52^{M}$).

3.4.3 Secondary Outcome Measures

3.4.3.1 Quality of Life

The overall PDQ-39 SI revealed a strong tendency for a statistically significant treatment effect in the EXP group (Table 3.2), as well as an improvement in perceived health status in the EXP group from pre- to post-intervention ($p = 0.04$; $d = 0.26^{S}$).

3.5 Discussion

To the researcher's knowledge, this is the first investigation that studied the effects of a SSTP on JPS and sensory integration in individuals with PD. The results suggest that the SSTP is a safe modality of training which can occur in group setting and holds the potential to improve QoL and sensory integration in individuals with PD. The EXP enjoyed the SSTP and found it very interesting, useful and of value (Figure 3.1), also no adverse events were reported. When analysing the results, it should be noted that some significant and large percentage differences are accompanied by small practical changes, which could possibly be attributed to a large variation within groups.

Changed scores related to JPS were observed in both groups, and even though there was no treatment effect, the EXP showed significant improved absolute error scores after the Treatment phase (Table 3.2). This finding is in contrast to Haas et al. [112] who found no significant improvements in JPS after somatosensory stimulation (WBV) in individuals with PD. However, even though the PBO did not improve their JPS significantly, they did show the same practical improvement as EXP. Nonetheless, Haas et al. [112] stated that one should keep in mind the general aspects and difficulties of assessing proprioception and it might be worthwhile to further investigate the AMEDA to see whether a learning effect might be evident.

One of the best parameters for evaluating PS in PD subjects is JERK. The parameter JERK indicates the relative smoothness of PS, reflecting the amount

Table 3.2: Change in scores between Baseline and Treatment phases for PBO and EXP for all outcome measures.

	Placebo group (n = 13)					Experimental group (n = 24)					
	Mean (SEM)			Mean difference (95% CI)		Mean (SEM)			Mean difference (95% CI)		p
	Baseline	Pre	Post	Pre-Baseline	Post-Pre	Baseline	Pre	Post	Pre-Baseline	Post-Pre	TE
JPS Absolute error	1.0	0.92	0.82	-0.09	-0.09	0.88	0.89	0.78	0.01	-0.11*	0.40
	(0.05)	(0.06)	(0.06)	(-0.25 to 0.09)	(-0.27 to 0.07)	(0.04)	(0.06)	(0.04)	(-0.13 to 0.15)	(-0.34 to -0.06)	
JERK (overall) [Log^]											
1. EO	0.37	0.24	0.20	-0.13	-0.04	0.17	0.23	0.20	0.06	-0.03	0.32
	(0.16)	(0.06)	(0.03)	(-0.47 to 0.21)	(-0.18 to 0.10)	(0.03)	(0.06)	(0.05)	(-0.08 to 0.20)	(-0.19 to 0.13)	
2. EC	0.96	0.92	0.81	-0.04	-0.11	1.49	1.13	0.63	-0.36	-0.50	0.60
	(0.24)	(0.22)	(0.12)	(-0.71 to 0.63)	(-0.62 to 0.40)	(0.79)	(0.62)	(0.17)	(-2.38 to 1.66)	(-1.80 to 0.80)	
3. EO+F	0.69	0.53	0.60	-0.16	0.07	0.27	0.24	0.23	-0.03	-0.01	0.74
	(0.17)	(0.14)	(0.17)	(-0.62 to 0.30)	(-0.39 to 0.53)	(0.05)	(0.05)	(0.1)	(-0.18 to 0.12)	(-0.16 to 0.14)	
4. EC+F	4.58	3.98	5.46	-0.60	1.48	5.50	4.87	1.50	-0.63	-3.37*	0.0002*
	(1.50)	(1.15)	(1.28)	(-4.47 to 3.27)	(-2.07 to 5.03)	(2.51)	(2.56)	(0.38)	(-7.83 to 6.57)	(-8.58 to 1.84)	
Root Mean Square (overall) [Log^]											
1. EO	0.07	0.06	0.07	-0.01	0.01	0.07	0.07	0.08	0.00	0.01	0.11
	(0.01)	(0.01)	(0.01)	(-0.03 to 0.01)	(-0.02 to 0.04)	(0.01)	(0.01)	(0.01)	(-0.03 to 0.03)	(-0.02 to 0.04)	
2. EC	0.12	0.12	0.12	0.00	0.00	0.13	0.15	0.10	0.02	-0.05	0.59
	(0.05)	(0.01)	(0.02)	(-0.04 to 0.04)	(-0.04 to 0.04)	(0.03)	(0.04)	(0.01)	(-0.09 to 0.13)	(-0.14 to 0.04)	
3. EO+F	0.10	0.10	0.09	0.00	-0.01	0.09	0.09	0.11	0.00	0.02	0.10
	(0.01)	(0.01)	(0.01)	(-0.03 to 0.03)	(-0.04 to 0.02)	(0.01)	(0.01)	(0.02)	(-0.04 to 0.04)	(-0.02 to 0.06)	
4. EC+F	0.26	0.25	0.25	-0.01	0.00	0.29	0.27	0.20	-0.02	-0.07*	0.08
	(0.04)	(0.03)	(0.02)	(-0.11 to 0.09)	(-0.07 to 0.07)	(0.05)	(0.05)	(0.02)	(-0.16 to 0.12)	(-0.18 to 0.04)	
Centroidal Frequency (overall) [Log^]											
1. EO	1.11	1.13	1.10	0.02	-0.03	0.96	1.03	0.89	0.07	-0.14*	0.35
	(0.09)	(0.08)	(0.07)	(-0.23 to 0.27)	(-0.24 to 0.18)	(0.05)	(0.05)	(0.04)	(-0.08 to 0.22)	(-0.28 to 0.00)	
2. EC	1.08	1.06	1.07	-0.02	0.01	0.92	0.96	0.96	0.04	0.00	0.79
	(0.06)	(0.06)	(0.05)	(-0.19 to 0.15)	(-0.15 to 0.17)	(0.04)	(0.04)	(0.04)	(-0.07 to 0.15)	(-0.12 to 0.12)	
3. EO+F	1.12	1.02	1.12	-0.10	0.10	0.89	0.82	0.81	-0.07	-0.01	0.19
	(0.09)	(0.11)	(0.09)	(-0.41 to 0.21)	(-0.20 to 0.40)	(0.05)	(0.04)	(0.05)	(-0.21 to 0.07)	(-0.15 to 0.13)	
4. EC+F	1.07	0.99	1.20	-0.08	0.21	0.87	0.85	0.85	-0.02	0.00	0.12
	(0.08)	(0.09)	(0.09)	(-0.32 to 0.16)	(-0.05 to 0.47)	(0.06)	(0.06)	(0.05)	(-0.19 to 0.15)	(-0.16 to 0.16)	
PDQ-39 SI	4.57	3.56	4.15	-1.01*	0.59	4.43	4.18	3.55	0.12	-2.75*	0.06[#]
	(1.01)	(0.93)	(0.89)	(-3.83 to 1.81)	(-2.06 to 3.24)	(0.53)	(0.55)	(0.48)	(-1.78 to 1.26)	(-2.09 to 0.83)	

Abbreviations: ADL: Activities of Daily Living; CI: Confidence Interval; EC: Eyes Closed; EO: Eyes Open; F: Foam; JPS: Joint Position Sense; PDQ-39 SI: Parkinson's Disease Quality of Life Questionnaire Summary Index; SEM: Standard Error of Mean; SI: Summary Index; TE: Treatment Effect. [Log:]Analysis performed on log-transformed data. [^]Baseline: n = 12 for PBO group. *Indicates statistical significance ($p < 0.01$). [#]Indicates strong tendency ($p = 0.06$).

of active postural corrections, and is interpreted as a measure of dynamic stability [3]. Other valuable parameters are CF, which gives an indication of frequency of sway [3], and RMS which gives the amplitude of PS movements, or sway area [10].

A treatment effect was observed in JERK during condition 4 (Table 3.2), where vestibular information was the primary source of reliable feedback in order to maintain PC. The vestibular system is a principal proprioceptor, which helps monitor one's own capability to maintain balance [29] and observations have been made that proprioceptive disturbances could contribute to balance and motor deficits in PD [137]. Movement disorders, such as PD, predominantly results from basal ganglia dysfunction, and since this disease shows increased sensory abnormalities, it suggests that the pathophysiology involves the sensory system [81]. Additionally, studies have provided evidence that loss of neurons in the thalamus, which projects to the sensory-motor regions [82, 83], and hyperactivation of the cerebellum, could be the cause of impaired automatic movements [84]. Thus, not only the basal ganglia, but also the cerebellum, thalamus and their connections receive altered sensory information and leads to abnormal sensory-motor integration [81]. The EXP showed less jerkiness compared to the PBO during condition 4 after the Treatment phase, and EXP showed improved JERK, CF and RMS during post-intervention. This could be attributed to the fact that the SSTP might alter an individual's ability to control their motor system when they are restricted to only using vestibular cues to maintain PC. Furthermore, proprioceptive feedback was disturbed during this condition because the individuals had to stand on foam. Thus, the assumption that the SSTP helped the individuals to override faulty proprioceptive feedback and rather focus on reliable vestibular cues to maintain PC. This mode of training could hold the potential to improve an individual's ability to integrate sensory information and thus enable individuals to utilise more of the sensory information, assisting in safer interactions with the surrounding environment [118].

During condition 3, proprioception was altered and individuals could only rely on the visual and vestibular system. Individuals with PD are known to be visually dependent [80], which might explain the consistent results seen over time in condition 3. There was a consistent group difference over all three testing periods for JERK and CF, because both groups showed similar results throughout the Baseline and Treatment phases. Thus, the assumption can be made that the PBO participants were more proprioceptive dependent than the EXP group, because they consistently presented with higher JERK and CF values and that when PD individuals receive visual feedback, their performance stays the same overtime. Consequently, the SSTP did not improve the ability to use visual feedback better, but more the integration of sensory information in individuals with PD.

There were no significant intragroup differences between the baseline and pre-intervention in PS, thus only the differences between conditions before and after the intervention within the respective group were analysed. Overall JERK showed a larger PS during conditions without vision compared to conditions with vision in both EXP and PBO, which could contribute to the notion that individuals with PD are visually dependent. According to Tagliabue et al. [80], the visual dependency observed in individuals with PD could be due to the observation that their proprioception is impaired. This occurrence is supported by the fact that both groups had more jerkiness and frequency of sway during condition 2 and 4 where eyes were closed, regardless of the surface area, compared to condition 3 where eyes were open but individuals stood on the compliant surface area. Thus, even though individuals stood on the floor but with eyes closed (condition 2) they performed worse, as to when they stood on foam with their eyes open (condition 3).

A similar pattern was found for RMS when compared to JERK, except that there was no significant difference in sway amplitude during eyes closed (condition 2) compared to eyes open on foam (condition 3) for EXP in the post-intervention. Thus after the intervention, EXP had less sway during condition 2, causing a reduction in the difference between the two conditions. Less amplitude of sway during this condition could be indicative of improved proprioception, but because this is the only case, more research remains warranted.

Overall QoL, as measured by the PDQ-39 SI, improved in EXP which suggests that SSTP could address well-being and mobility issues seen in PD. According to Jenkinson et al. [145], the PDQ-39 SI gives an indication of the impact of the illness on functioning and well-being by providing a summary score which could be of use in the evaluation of the overall effect of different interventions.

To conclude, the study results suggest that a SSTP may improve JPS as well as sensory integration in individuals with PD, proposing enhanced body orientation leading to improved PC and improved QoL [138]. Two distinct mechanisms produced positive changes in individuals with PD: (1) SSTP altered the ability to control the motor system when the primary source of reliable feedback was the vestibular system; and (2) training helped subjects to override faulty proprioceptive feedback and utilise reliable visual or vestibular cues [148]. The application of a somatosensory training could be useful in improving PC and reducing fall risk in individuals with PD. Future research should focus on recruiting a larger sample size as well as conducting a randomised controlled trial.

Chapter 4

Article 2

Eight-week somatosensory training improves mobility and fear of falling in individuals with mild to moderate Parkinson's disease

4.1 Abstract

Introduction: Deficits in proprioception have a negative effect on postural control, but the precise contribution to postural instability in Parkinson's disease remains unclear. Researchers investigated whether an eight-week somatosensory training program will influence mobility and fear of falling in individuals with Parkinson's disease.

Methods: Thirty-seven individuals with idiopathic Parkinson's disease (67 $\pm$ 9 years; Hoehn&Yahr: 2 $\pm$ 1) were divided into two groups i.e. somatosensory experimental group (n = 24) and placebo group (n = 13). The Timed-Up-and-Go, Fall Efficacy Scale-International, Movement Disorder Society-Unified Parkinson's Disease Rating Scale part III and total score were assessed at baseline, before and after the intervention.

Results: A treatment effect was found in Timed-Up-and-Go (p = 0.0001), Fall Efficacy Scale-International (p = 0.02), part III (p = 0.02), as well as in total score of Movement Disorder Society-Unified Parkinson's Disease Rating Scale (p = 0.02) for experimental. The experimental group improved in the Timed-Up-and-Go over the Treatment phase (p = 0.001). Additionally, the experimental group showed better Timed-Up-and-Go times after the intervention (p = 0.01), compared to placebo.

Conclusions: The positive findings of this study provide evidence that this somatosensory training program can improve mobility, fear of falling, motor functionality as well as disease severity in Parkinson's disease individuals.

Keywords: Dynamic balance; Fear of falling; Postural control; Somatosensory training.

4.2 Introduction

Parkinson's disease (PD) is a progressive disease of the nervous system, which results in motor and non-motor symptoms i.e. resting tremor, bradykinesia, muscular rigidity, slow, imprecise movement, depression and cognitive impairment [42]. Prospective studies suggest that up to 70% of individuals with PD experience falls over one year, and that 10% report falling more than once per week. Falls and impaired movement are dangerously affecting Quality of Life (QoL) and are common sources of disability in individuals with PD [54]. Yardley & Smith [149] described fear of falling as an on-going concern about falling, reduction in balance confidence, decreased fall-related self-efficacy, or as activity avoidance. Adkin and colleagues [150] showed that fear of falling was more evident in individuals with PD, compared to healthy elderly individuals.

Postural control (PC), more commonly known as balance, is the ability to maintain an unsteady equilibrium while the muscles work against gravity [151]. Parkinson's disease is known to cause alterations in PC strategies as a result of the underlying physical cause related to the disease process [59]. These changes in PC has been said to increase levels of fear of falling and restrict activity [150]. Balance is a complex interaction between the individual's musculoskeletal and neural system, the task and environment. According to Woollacott [152], the body's centre of mass has to be maintained over its base of support, inside the limits of stability. However, since individuals with PD experience problems with the interaction between the musculoskeletal and neural system, they find it difficult to maintain this equilibrium. Yang et al. [153] explained that PC during locomotion requires the integration of various sensory and motor pathways, which would allow the central nervous system to coordinate the postural and movement aspects.

Sensory input from the somatosensory (i.e. tactile and proprioception), visual and vestibular system are essential to maintain PC [154]. Recent research however states that basal ganglia dysfunction, as in PD, shows increased sensory abnormalities, which suggests that the pathophysiology involves the sensory system [81]. Individuals with PD have deteriorated somatosensory function [155, 31], which includes impaired haptic feedback [42] as well as poor proprioception [79, 78]. Dynamic balance refers to the ability to continuously control the centre of mass as the base of support is changing like observed during gait and postural transitions [70]. In other words, an adult must be able to maintain dynamic balance during many functional activities which they would use daily, such as walking. Maintaining balance during walking requires the integration of postural adjustments into the step cycle in order to allow safe forward movement. In this dynamic task the centre of mass is not maintained within the base support, but moves along the medial border of

the support foot. This integration of PC onto voluntary activities is essential to the accomplishment of most goal orientated tasks and requires the ability to adapt to constantly changing environmental and task demands [8].

According to Salgado and colleagues [42] exercise appears to have a neuroprotective effect against developing PD. Recent findings support that intensive and challenging exercises induce neuroplasticity, suggesting that exercise is becoming essential in PD treatment [127, 128]. Dopaminergic medications are often insufficient to assist postural instability [23], which is supported by Jöbges and colleagues [131], who stated that, medication fails to improve balance in PD individuals, leading to compensation for these postural instabilities.

Developing efficient, sustainable programs for individuals with PD will ultimately lead to improving their QoL as well as lessening the demands on health care systems. Results from Nilsson and colleagues [156], state that walking difficulties should be the main target in training sessions for individuals with PD in order to reduce fear of falling and improve QoL. Specifically, dynamic balance, climbing stairs and turning, also referred to as mobility, are of extreme importance [156]. To date, no research has investigated the effect of a somatosensory training program (SSTP) on mobility and fear of falling in individuals with PD. Given the high incidence of fall-related injuries within this population, it is vital to implement on-going assessment of postural stability as well as non-pharmacological interventions for disease management and improved QoL [48]. Therefore, the study set out to assess whether an eight-week SSTP will influence mobility and functional balance as well as concern for fear of falling in individuals with mild to moderate PD.

4.3 Methods

4.3.1 Study Design

This was a time series experimental study with a sample of convenience which included two eight-week phases, namely Baseline (baseline to pre-intervention) and Treatment phase (pre- to post-intervention). Local newspapers and support groups within a 50 km radius from Stellenbosch University (South Africa) were used to recruit participants. Individuals were either divided into the placebo group (PBO), who had to wear a wristband during the Treatment phase, or into the experimental group (EXP), who participated in an eight-week SSTP. Participants were assessed either in their home, or in the Movement Laboratory (Stellenbosch University) while on medication, and the order of measurements was standardised. The total testing period for both groups was 16-weeks and both groups were tested three times i.e. baseline, pre-intervention and post-intervention. All assessments were done by the same

person, at the same time, throughout the baseline and Treatment phase.

4.3.2 Participants

The study was approved by the Institutional Research Ethics Committee (HS1041/201). All participants gave informed consent and tests were conducted with professionalism as well as in accordance with the *Declaration of Helsinki*. Participants were included if they were over the age of 50, diagnosed with mild to moderate idiopathic PD, and lived an independent-living lifestyle, in other words, had a severity level of I-III on the Hoehn and Yahr scale (H&Y) [20] or a Movement Disorder Society-Unified Parkinson's Disease Rating Scale (MDS-UPDRS) part III score of < 59 [7]. Participants who had history of any other neurological conditions other than PD, visual and vestibular problems or moderate cognitive impairment defined as < 17 on the Montreal Cognitive Assessment (MoCA) [143], were excluded. Participants had to attend $\geq 70\%$ of the exercise sessions and could not miss more than two consecutive sessions.

4.3.3 Intervention

Each individual acted as their own control for the first eight weeks of the study. This was done to measure the baseline of each participant as well as to look at the effect of time on each individual before the intervention started. Individuals were not allowed to do any additional physical activities during the Treatment phase compared to what was done during the Baseline phase.

The EXP participants were asked to partake in a $30-60$ minute SSTP for an eight-week period, with three sessions every week, each progressively increasing in complexity and difficulty. Sessions started with 10-minute warm-up, followed by $15-40$ minutes (dependent on week) of challenging somatosensory training blocks, and ended with 5 minutes cool-down and relaxing techniques. Individuals were given short rest breaks when required and all the exercise sessions were instructed by two clinical Exercise Therapists (biokineticists).

The PBO group was given a wristband to wear over the Treatment phase and was told that they should stand upright and focus on their balance when they notice it. The PBO participants received a SSTP DVD after completing the study interventions.

4.3.4 Outcome Measures

The primary outcome measure was mobility and functional balance, which was determined using the Timed-Up-and-Go (TUG) [157]. Concern for falling during activities of daily living, whether it is social or physical activities, were

assessed with the Fall Efficacy Scale-International (FES-I) [149].

Secondary outcome measures included Part III (Motor Examination) and the total score of the MDS-UPDRS [129].

4.3.5 Data Analysis

Descriptive statistics are reported as mean and standard deviation (± SD), whereas graphs are reported as mean and Standard Error of Mean (SEM) unless otherwise specified. The comparison between the EXP and PBO groups' mobility and functional balance, fear of falling and motor scores were analysed with a mixed model repeated measures ANOVA's and a Fisher Exact LSD post-hoc analysis over the two eight-week phases. Data was assessed using normal probability plots and log transformations were done where data was not normally distributed. Level of significance was set at $\alpha = 0.05$. Cohen's effect sizes (d) [147] were used to determine the practical differences between the groups. Abbreviations used for defining effect sizes included the following: $^{\mathrm{N}}$: Negligible; $^{\mathrm{S}}$: Small; $^{\mathrm{M}}$: Medium; $^{\mathrm{L}}$: Large; $^{\mathrm{VL}}$: Very large; d_{base}: baseline; d_{pre}: pre-intervention and; d_{post}: post-intervention values. Data was analysed using the STATISTICA for Windows version 12 (StatSoft, Inc., Tulsa, OK, USA) software. One of the participants in the PBO group could not complete the TUG, thus the sample size was 12 for the PBO group during all three assessments.

4.4 Results

4.4.1 Baseline Characteristics

The demographic characteristic of the participants is presented in Table 4.1, and no differences were found between the groups ($p > 0.05$). There were no significant group differences in TUG, FES-I as well as total score of MDS-UPDRS ($p > 0.05$) at baseline. The PBO group presented with a better part III MDS-UPDRS score during baseline, showing a group difference of 39% ($p = 0.05$; $d = 0.66^{\mathrm{M}}$). The EXP group showed a 10% reduction in TUG time after the Baseline phase ($p = 0.002$; $d = 0.37^{\mathrm{S}}$, whereas the PBO changed by 2% from baseline to pre-intervention ($p = 0.63$; $d = 0.05^{\mathrm{N}}$). For the FES-I, the EXP showed a 7% reduction ($p = 0.25$; $d = 0.22^{\mathrm{S}}$) and PBO group a 2% reduction after the Baseline phase ($p = 0.52$; $d = 0.06^{\mathrm{N}}$). During the Baseline phase, the EXP presented 1% reduction for both part III ($p = 0.78$; $d = 0.02^{\mathrm{N}}$) and total score of the MDS-UPDRS ($p = 0.77$; $d = 0.03^{\mathrm{N}}$). The PBO group increased their performance score from baseline to pre-intervention, showing a 5% poorer score for both part III ($p = 0.50$; $d = 0.11^{\mathrm{N}}$) and total score ($p = 0.14$; $d = 0.20^{\mathrm{S}}$).

Table 4.1: Demographic characteristics of participants in PBO and EXP groups (mean ± SD).

Variable	Placebo group (n = 13)	Experimental group (n = 24)
Age (years)	71 ± 10	65 ± 8
Sex (men)	8 (62%)	15 (63%)
Weight (kg)	78 ± 17	80 ± 17
Height (m)	1.8 ± 0.1	1.7 ± 0.1
BMI (kg/m^2)	28 ± 5	29 ± 6
PD Level (H&Y)	2 ± 1	2 ± 1
MDS-UPDRS III	23 ± 12	31 ± 14
MoCA	25 ± 3	24 ± 3
Exercise (hr/wk)	2.1 ± 1.7	1.8 ± 1.5

Abbreviations: BMI: Body Mass Index; EXP: Experimental group; H&Y: Hoehn and Yahr scale; MDS-UPDRS: Movement Disorder Society-Unified Parkinson's Disease Rating Scale; MoCA: Montreal Cognitive Assessment; PBO: Placebo group.

4.4.2 Exercise Adherence, Drop-outs and Adverse Events

Forty-four individuals met the study inclusion criteria, however only 37 participants completed the study. Three participants of EXP were excluded because they did not attend 70% of prescribed exercise sessions. The average sessions attended by EXP were 21.3 ± 2.3. Two participants were excluded after falling during the Treatment phase (but not because of SSTP), another due to medication changes, and one participant withdrew from the study due to health problems. No other adverse events were reported, and where necessary the SSTP was modified according to the capabilities of each participant.

4.4.3 Effect of Intervention

A significant treatment effect was found in the TUG (p = 0.0001), FES-I (p = 0.02), part III (p = 0.02) as well as in the total score of the MDS-UPDRS (p = 0.02) in the EXP group. After the Treatment phase the EXP group showed an 11% improvement (p = 0.001; $d = 0.41^{M}$), whereas PBO indicated a 5% deterioration from pre- to post-intervention (p = 0.21; $d = 0.11^{N}$) in the TUG (Figure 4.1). For the FES-I, the EXP showed a 6% reduction after the Treatment phase (p = 0.10; $d = 0.20^{S}$), whereas the PBO group revealed a 9% increase after the Treatment phase (p = 0.09; $d = 0.32^{S}$) for fear of falling (Figure 4.2). After the Treatment phase the EXP showed 5% and 6% reduction for part III (p = 0.27; $d = 0.12^{N}$) and total score (p = 0.15; $d = 0.17^{S}$),

respectively. Placebo continued to worsen after the Treatment phase in part III (p = 0.07; $d = 0.28^{S}$) (Figure 4.3) and total score (p = 0.41; $d = 0.17^{S}$) (Figure 4.4) with 14% and 9%, respectively.

Looking at group differences, during the TUG there was a significant group difference of 29% after the Treatment phase (p = 0.01; $d = 0.95^{L}$). There were no significant group differences in FES-I as well as and total score of MDS-UPDRS (p > 0.05) for pre- or post-intervention. However, there was 1% group difference for FES-I during pre-intervention (p = 0.99; $d = 0.04^{N}$), whereas post-intervention revealed a 16% group difference (p = 0.11; $d = 0.52^{M}$). The same pattern was seen during pre-intervention as in baseline for MDS-UPDRS, however groups were more similar showing 31% and 9% difference for part III (p = 0.10; $d = 0.60^{M}$) and total MDS-UPDRS (p = 0.57; $d = 0.19^{S}$), respectively. After the Treatment phase individuals only differed by 9% for part III (p = 0.57; $d = 0.20^{S}$) and 6% for total MDS-UPDRS score (p = 0.69; $d = 0.16^{S}$).

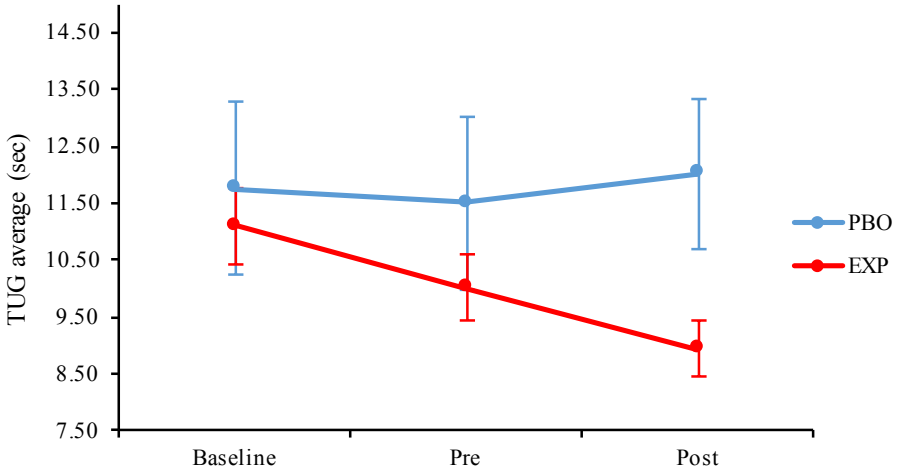


Figure 4.1: Timed-Up-and-Go scores for EXP and PBO from baseline to post-intervention (mean and SEM).

4.5 Discussion

This study shows that a SSTP may improve mobility and functional balance, fear of falling as well as motor symptoms in individuals with PD. The SSTP produced statistically significant treatment effects in both primary outcome measures, TUG and FES-I, as well as in secondary outcome measures, part III and total score of MDS-UPDRS.

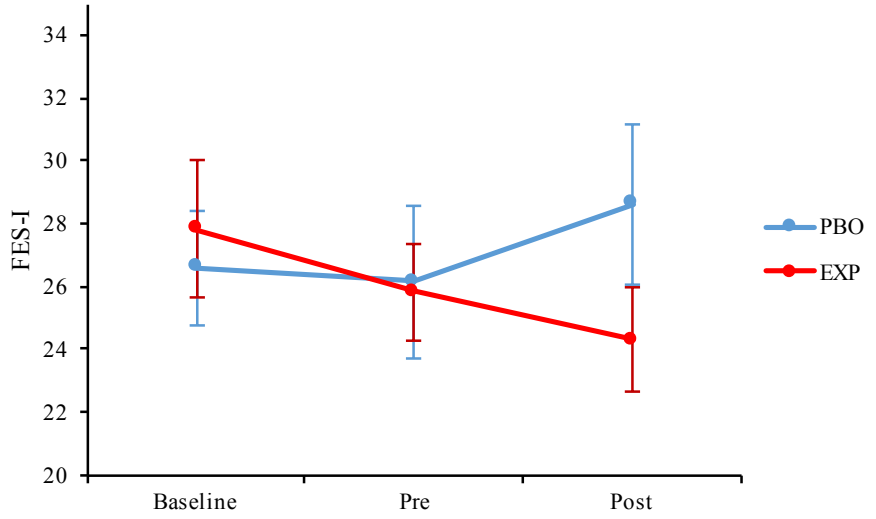


Figure 4.2: Fear for falling scores for EXP and PBO from baseline to post-intervention (mean and SEM).

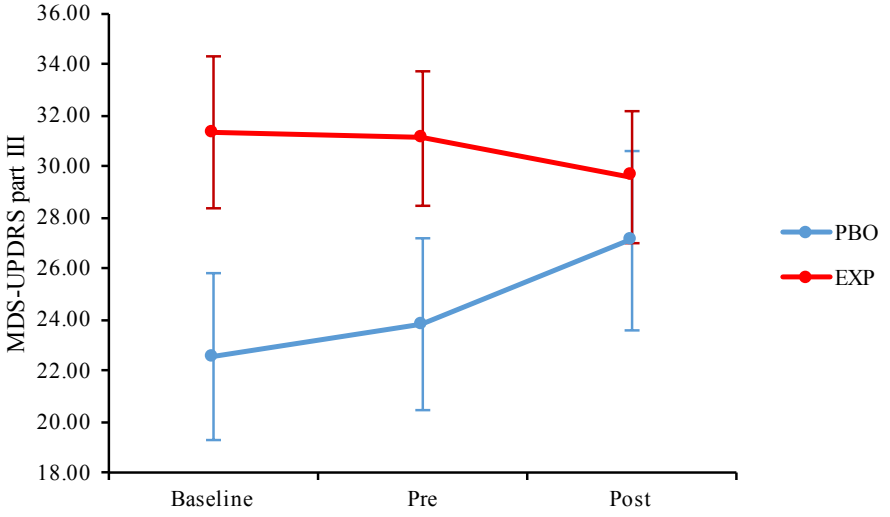


Figure 4.3: Motor functionality scores for EXP and PBO from baseline to post-intervention (mean and SEM).

The TUG assesses mobility and functional balance in PD which may help to establish risk for falls and whether a rehabilitation program is effective [157, 100]. The TUG is a moderately complex task for individuals with PD, requiring them to stand up from a chair, walk three meters, turn 180°, walk back to the chair and sit down. The EXP group improved similarly in their TUG with 1.1sec after the Baseline phase and 1.06 sec after the Treatment

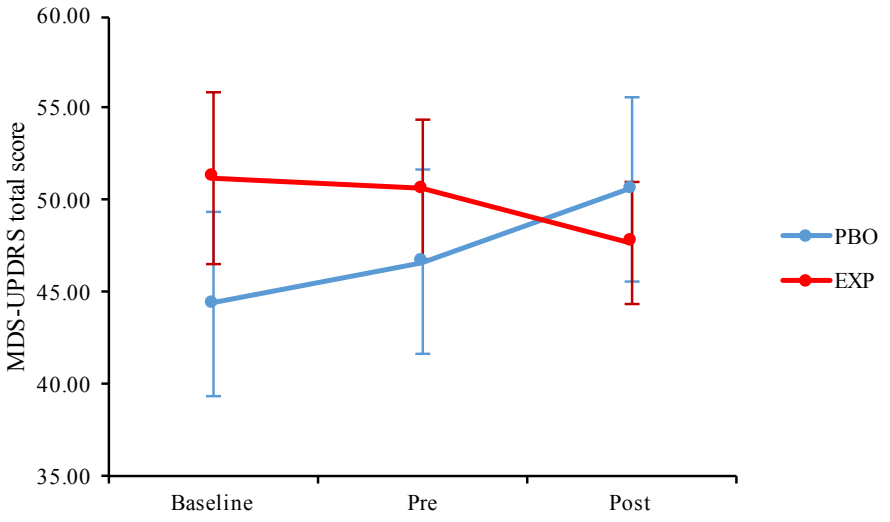


Figure 4.4: Overall disease severity scores for EXP and PBO from baseline to post-intervention (mean and SEM).

phase. This could be attributed to increased motivation prior to commencing the Treatment phase, or it could indicate a possible learning effect within the group. Contrarily, PBO improved slightly after the Baseline phase (0.26 sec), but worsened in performance after the Treatment phase (0.52 sec), although nothing statistically significant. Nevertheless, there was a significant group difference, only during post-intervention, suggesting that the EXP group maintained their mobility whereas the PBO groups' mobility deteriorated. This could be attributed to the progressive nature of PD. Research has shown that the average TUG time for PD-fallers are 12.21 $\pm$ 7.42 sec, whereas PD non-fallers score on average 7.94 $\pm$ 2.15 sec [100]. According to these norms, the PBO group was closer to the fallers category after the intervention whereas EXP was closer to the non-fallers category. Thus the SSTP may improve mobility and functional balance in individuals with PD.

The same pattern was seen in concern for falling as in TUG for both groups, and research shows a positive correlation between FES-I and TUG in elderly individuals [158]. Even though fear of falling is seen as a protective mechanism, it has the potential to lead to social isolation and restricted mobility, contributing to reduced functional ability as well as an actual increase in risk for falling [159]. According to Almeida et al. [29], a score of $>$ 30 on the FES-I could identify individuals at higher risk for falls as well as profile them as possibly becoming recurrent fallers. Before the Treatment phase commenced, both groups' FES-I scores were above 25, yet after the Treatment phase EXP scored below 25 whereas PBO was even closer to 30 (Figure 4.2) Even though there were no significant intragroup or intergroup changes, the higher per-

centage group difference and medium effect size after the Treatment phase, could indicated less concern for falling in EXP. This study warrants the execution of a larger trial with the same intervention protocol to assess whether these relative small improvements in FES-I translates to reduced fear of falling.

The total MDS-UPDRS score presents overall PD severity, whereas part III on this scale gives an indication of motor functioning. According to Goetz et al. [129], each part of the MDS-UPDRS can be considered separately, because the factor structures are clinically relevant. Both groups showed little change during the Baseline phase ($\leq 5\%$), yet after the Treatment phase the EXP improved their scores whereas the PBO reduced their scores ($\geq 5\%$). Once again the conclusion can be made that the EXP group were able to maintain their motor functioning and severity level with the SSTP, whereas the PBO group deteriorated over time as PD is a progressive neurological disorder. Disease severity correlates well to fear of falling and mobility, which are key factors related to falls [159]. Although none of these changes were significant, the treatment effect in both part III and total score, suggests that the SSTP improves the overall PD severity as well as improves motor functioning level in PD individuals.

There are a few limitations in this study that need to be elaborated on. Firstly, individuals were tested on medication. Thus, future studies should attempt to assess PD participants both on and off medication, to document the full spectrum of functional mobility and balance. Subjects were recruited form a sample of convenience and the sample size was relatively small. Thus, individuals may not be a true representation of all individuals with PD and future studies would benefit from random sampling. Despite these limitations, the results from this study suggest that a SSTP could hold several benefits for individuals with PD.

Researchers conclude that by incorporating somatosensory exercises into a balance training program, functional balance needed for everyday mobility, fall risk and motor functioning may be improved.

Conflict of Interest

The authors declare that they have no conflict of interest.

Chapter 5

Article 3

Somatosensory training improves sensory integration but not haptic feedback in individuals with mild to moderate Parkinson's disease

5.1 Abstract

Objective: To examine whether light haptic feedback would influence postural sway (PS) and if eight-weeks of somatosensory training program (SSTP) can alter the haptic feedback influence on PS in individuals with Parkinson's disease (PD).

Design: Time-series experimental study design with a sample of convenience. Participants were assessed on medication at baseline, pre- and post-intervention.

Setting: University Movement Lab setting.

Participants: Thirty-seven individuals with idiopathic PD (67 $\pm$ 9.03 years; Hoehn&Yahr: 2.12 $\pm$ 0.67; MDS-UPDRS part III: 28 $\pm$ 14) were divided into two groups i.e. somatosensory training (EXP; n = 24) and placebo group (PBO; n = 13).

Intervention: An eight-week SSTP emphasising somatosensory training blocks, performed three times per week, each progressively increasing in complexity and difficulty.

Main Outcome Measures: Postural sway was assessed with the Instrumented Sway tri-axial accelerometer to assess Root Mean Square (RMS) during 4 sensory conditions i.e. eyes closed with no manual contact, eyes closed with light haptic feedback, both on a foam pad. Secondary outcome measures were balance confidence and motor experiences of daily living.

Results: Both groups presented with reduced sway amplitude when receiving haptic feedback compared to no manual contact, regardless of the surface area ($p < 0.01$). EXP improved sensory integration ($p = 0.01$) and showed a tendency for improved balance confidence ($p = 0.07$) and motor experiences of daily living ($p = 0.05$) at post-intervention.

Conclusion The SSTP did not alter the influence of haptic feedback, but

it holds the potential to improve sensory integration, balance confidence and motor experiences of daily living in individuals with PD. Light haptic feedback improves PS in individuals with PD, regardless of the surface area.

Keywords: Parkinson's disease, Haptic feedback, Somatosensory training, Sensory-motor system, Independent-living.

5.2 Introduction

Postural control (PC) is a complex perceptual-motor process that allows an individual to maintain their balance through feedback and feed-forward mechanisms from visual, vestibular and the somatosensory systems [58]. Healthy adults rely predominantly on somatosensory information for balance in illuminated and stable surface environments [13]. Haptic (including tactile and kinaesthetic) feedback provided when touching an external surface may enhance somatosensory information [92]. The cutaneous mechanoreceptors and kinaesthetic receptors influence movement-related characteristics in motor skill and motor control, such as movement accuracy, consistency and force adjustments [160]. Haptic feedback intermittently updates the central nervous system movement command centre to adjust movements [161].

Proprioceptive integration, feedback for movement [162] and PC [137] are reported to be impaired in individuals with Parkinson's disease (PD) [91]. Proprioception is essential for the correct interpretation of cutaneous/tactile feedback [163] and for PC [28, 25] This suggests that individuals with PD may not accurately interpret haptic feedback [42]. As compensatory strategy, for the impaired proprioceptive feedback [141], individuals with PD are often more reliant on continuous visual information compared to healthy individuals to complete different motor tasks, e.g. walking [164, 75, 133, 80, 165]. However, Rabin and colleges [92] found that haptic feedback improved postural sway (PS) in individuals with PD equally on and off medication, and when using either side of their body to lightly touch (< 1 N) a pressure plate. The researchers concluded that PD or associated dopaminergic pathways do not directly affect haptic feedback balance control mechanisms. In other words, haptic feedback could control balance via non-dopaminergic pathways and the integration of proprioception with tactile feedback in static balance may be impartial of dopaminergic pathways impaired by PD or levodopa medication.

In spite of advances in pharmacological treatments, PC problems become increasingly more debilitating as PD progresses [166]. Overall postural instability could be partly attributed to the declining effectiveness of dopaminergic therapy or levodopa replacement therapy reducing muscle tone which contributes in the deterioration of balance [23, 167, 168]. This suggests that

non-dopaminergic pathways, specifically from the basal ganglia to brainstem centres, are probably involved in PD PC [23, 166].

Baldan et al. [160] reviewed the use of light touch to improve postural stability in individuals with balance disorders compared to healthy individuals and concluded that exercise scientist should explore interventions with haptic feedback to improve balance. According to the researchers' knowledge no study to date has determined whether a somatosensory training program (SSTP) could purposefully alter the haptic feedback to enhance postural stability. The researchers hypothesise that if haptic feedback relies on non-dopaminergic pathways for PC, then by incorporating somatosensory stimulation with balance training, individuals with PD may show improved sensory-motor integration and postural stability with added haptic feedback.

5.3 Methods

5.3.1 Participants and Sampling

Convenience sampling of 37 individuals with idiopathic PD was used in this time-series experimental study (Figure 5.1). Participants were recruited via newspapers, support groups and guest talks throughout the Western Cape (South Africa). Those participants who adhered to the inclusion criteria (Table 5.1) completed the 16-week study, which included two eight-week phases i.e. a Baseline and Treatment phase. The study was approved by the Institutional Research Ethics Committee (HS1041/201). Participants completed informed consent forms and personal information forms prior to participation. They were informed of any possible risks and discomfort they may experience, as well as that they may withdraw from the study at any time.

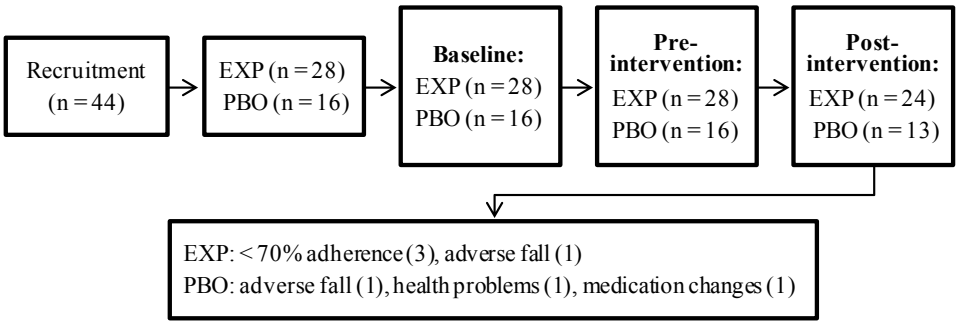


Figure 5.1: Illustration of study design.

Table 5.1: Inclusion and exclusion criteria for all participants.

Inclusion criteria	Exclusion criteria
• Men and women between the ages of $50 - 85$ years [169, 170].	• Other neurological conditions other than PD (e.g. Diabetes, stroke).
• Diagnosed with mild to moderate idiopathic PD, by their neurologist.	• Orthopaedic or muscular injuries.
• Independent-living lifestyle, defined as severity level of I-III on H&Y [6] or if H&Y IV have a MDS-UPDRS part III[a] score less than 59 [7].	• Moderate to severe cognitive impairment (a score $<$ 17 on the MoCA[b] [143]).
• Ability to stand tandem and execute dynamic balance activities.	• Less than 70% attendance of the exercise sessions.
	• Missing more than 2 consecutive exercise sessions.
	• Inability to perform exercises.
	• Any changes in medication during 16-week study.

Abbreviations: H&Y: Hoehn and Yahr scale; MDS-UPDRS: Movement Disorder Society - Unified Parkinson's Disease Rating Scale; MoCA: Montreal Cognitive Assessment; PD: Parkinson's disease. [a]:Items 18-31 on UPDRS, motor evaluation with possible maximum score = 108.[b]: 8 items evaluating Global cognition with possible maximum score = 30.

5.3.2 Study Design

Assessments were carried out at the participants' homes or at Stellenbosch University's movement laboratory, with all subjects tested on their anti-Parkinsonian medication cycle. Each participant underwent baseline, pre- and post-intervention measurements at the same place, sequence and assessor. Participants were divided into a placebo (PBO; n = 13) and experimental (EXP; n = 24) group.

5.3.3 Baseline and Treatment Phase

The first eight weeks, from baseline to pre-intervention (Baseline phase), each participant was their own control. The purpose was to explore the effect of time and learning on each individual when no intervention was applied. Participants were asked to log all their physical activities, so that when the Treatment phase started, that they didn't initiate any new activities besides which they have done in the Baseline phase. Pre- to post-intervention was the

Treatment phase during which the EXP group participated in a SSTP (Table 5.2) whereas the PBO group wore a deactivate activity monitor.

The SSTP intervention aimed to improve proprioception and sensory-motor integration [14] by manipulating sensory feedback during balance tasks. The SSTP was designed as an adaptation of Janda's sensory-motor training principles [97] and exercise guidelines of Conradsson et al. [121] for PD.

The PBO was blinded to the true purpose of the activity monitor and was instructed to use it as a balance feedback tool, also known as reinforcing behavioural feedback. Consequently, when they saw the wristband they had to focus on their posture and balance. However, unbeknownst to them (until after the Treatment phase) the activity monitor was never activated. In addition, PBO had to keep a weekly diary over the Treatment phase, in which they recorded their daily activities and balance-related problems.

Table 5.2: Outline of the SSTP.

Principles	**Exercise Prescription**
Frequency	Three days a week
Duration	$30 - 60$ minutes
Mode	Somatosensory stimulated activities i.e.
	Postural alignment and orientation
	Static balance exercises
	Dynamic balance exercises
	Functional balance exercises
Layout	Starting with 10 minutes light aerobic activities and stretching warm-up.
	Progressing from 15 to 40 minutes for somatosensory balance training.
	Concluding with 5 minutes cool-down and relaxing techniques.
Presented by	Clinical Exercise Therapist registered with the Health Professions Council of South Africa.

5.3.4 Baseline Assessments

During the first visit baseline data was collected for descriptive purposes such as age, height, as well as Parkinson's severity with the rating scales Hoehn and Yahr (H&Y) together with the Movement Disorder Society-Unified Parkinson's Disease Rating Scale III (MDS-UPDRS). Global cognition was assessed with the Montreal Cognitive Assessment (MoCA), since Rochester et al. [171] found that balance could be influenced by reduced attention and cognition. In addition, the completed personal information forms included information about their medication, activity status and PD history.

5.3.5 Main Outcome Measures

5.3.5.1 Postural Sway

The Instrumented Sway (ISway) protocol was adapted from Mancini et al. [3]. Throughout all trials participants were instructed to maintain an upright standing position, barefoot with feet in a modified tandem stance (15cm apart) and arms crossed at the chest. Each trial lasted for 30s and was executed once, during the following four conditions: (#1) eyes closed, no manual contact (EC+NMC); (#2) eyes closed, with haptic feedback (EC+HF); (#3) eyes closed, with haptic feedback on a foam (EC+HF+F) (#4) eyes closed, no manual contact on foam (EC+NMC+F). The tasks were performed either on a firm support surface (normal floor) or on a foam support surface (Airex Balance pad, Airex AG, Sins, Switzerland: 6.4×40.6×50.8cm, Density: 55kg/m^3 with ICC$= 0.41 - 0.81$, see [172]). The purpose of the foam was to reduce the effectiveness of lower limb proprioceptive inputs [173, 174]. Postural sway was measured by a tri-axial acceleration-based equipment including a gyro (inertial sensor) called the ISway. Data was capture as well as analysed with the Mobility Lab software (APDM Inc.; Mobility lab, Portland, USA). The approximate position of the body's centre of mass acceleration was recorded by the inertial sensor strapped at the fifth lumbar spine (L5; Figure 5.2) at a 90Hz sampling rate. Root mean square (RMS) of centre of mass acceleration in the overall, Anterior-Posterior (AP) and Medial-Lateral (ML) directions was calculated to represent body sway. The ISway has been validated against the gold standard force plate and found to be both valid and reliable ($r = 0.50 - 0.63$) [10].

Of the earliest studies on haptic feedback and PS, Jeka et al. [175] define non-mechanical supportive haptic feedback < 1 N (light touch), and also showed that "free touch" (allowing a person to choose their own applied force) was about 10 N and resulted in similar reduction as light touch. For the purpose of this study participants were instructed to lightly touch a kitchen scale (Page Evolution Silver, SOEHNLE, Germany; 13.2×20.7×0.99cm) with the haptic feedback threshold set at 10 N ($\pm$ 1000 g), similar to the protocol by Reginella et al. [176]. The kitchen scale acted as a pressure regulator and was

Figure 5.2: ISway sensor placement on L5 [174].

placed on a flat surface at hip height within arm's reach. A preliminary intervention by the same laboratory with the same < 10 N protocol also including a heavy touch (> 10 N) condition and found that overall, AP and ML RMS in 16 PD participants (68.7 $\pm$ 6.9 years; H&Y: 1.8 ± 0.8; 12 men:4 women) were significantly less when they used < 10 N haptic feedback compared to no manual contact and heavy touch.

5.3.5.2 Balance Confidence

Activity-specific Balance Confidence scale (ABC) was used to assess a participants perceived balance confidence during daily ambulatory activities. The 16-item questionnaire is quick and easy to administer, asking the client to indicate how confident they feel with a specific activity using a scale from 0% (no confidence) to 100% (complete confidence) [177, 178].

5.3.5.3 Motor Experiences of Daily Living

The MDS-UPDRS part II was used to assess motor experiences of daily living in participants. According to Rodriguez-Blazquez et al. [179], part II of the MDS-UPDRS is useful when assessing disability in PD. Researchers proposed cut-off values to easily interpret categories of disease severity namely, no disability $(0 - 2)$; mild $(3 - 16)$; moderate $(17 - 31)$; and severe (≥ 32) [179].

5.3.6 Statistical Analysis

Statistical analysis was performed using the STATISTICA for Windows version 12 (StatSoft, Inc., Tulsa, OK, USA) software. Descriptive statistics were calculated for all variables and reported as mean and standard deviation (± SD). A Shapiro-Wilks test for normality was done and if data was not normally distributed log transformations (Log) were done. Graphs are reported as mean ans Standard Error of Mean (SEM). Analyses were conducted using mixed model repeated measures ANOVA's, with group (EXP, PBO) as the intergroup factor and time (baseline, pre- and post-intervention) as the intragroup factor, and a Fisher Exact LSD post-hoc test. A significance level of $\alpha = 0.05$ was used, and $p < 0.10$ designating trends. Cohen's d effect sizes were calculated to determine meaningful changes i.e. 0.2^{S}: Small, 0.5^{M}: Medium and 0.8^{L}: Large [147].

5.4 Results

5.4.1 Participant Characteristics

Twenty-four participants with PD in EXP (age: 65 ± 8 years; height: 1.7 ± 0.1 m; weight: 80.0 ± 17.1 kg; sex: 15 men, 9 women; MoCa: 23.9 ± 2.8) and 13 demographically-matched individuals with PD in PBO (age: 71 ± 10 years; height: 1.8 ± 0.1 m; weight: 78.5 ± 17.3 kg; sex: 8 men, 5 women; MoCa: 24.7 ± 3.0) completed the study (N = 37). The EXP group's H&Y staging was as follows: Stage I (n = 6), Stage II (n = 12) and Stage III (n = 6) and average MDS-UPDRS III, 31 ± 14; whereas the PBOgroups' H&Y staging was as follows: Stage I (n = 4), Stage II (n = 8), and Stage IV (n = 1) and average MDS-UPDRS III, 23 ± 12. No significant differences were found between groups for age, height, weight, Parkinson's severity or global cognition ($p > 0.05$).

5.4.2 Main Outcome Measures

One PBO and two EXP participants' PS and ABC data, respectively, could not be used for baseline. Thus the data was omitted in the subsequent baseline calculations.

5.4.2.1 Postural Sway

Anterior-Posterior and ML RMS mostly followed the same pattern and statistical significance than overall sway. Thus only overall sway is illustrated and any difference in AP and ML sway from overall is reported in text. There were no time and between groups differences over the Baseline phase ($p > 0.05$) (Figure 5.3); thus only pre- (Figure 5.4) and post-intervention (Figure 5.5)

will be reported. Table 5.3 illustrates the p-values and effect sizes of the intragroup and intergroup differences between the four conditions for the two phases.

There was no group difference for any of the four conditions at pre- and post-intervention ($p > 0.05$). Between the conditions (Table 5.3) at pre-intervention, all participants presented with more PS during EC+NMC$^{\#1}$, compared to EC+HF$^{\#2}$ and EC+HF+F$^{\#3}$. Similar result was found at post-intervention for EC+NMC$^{\#1}$ compared to EC+HF$^{\#2}$ but not EC+HF+F$^{(\#3)}$. Contrary to overall RMS, PBO showed no difference during pre-intervention in ML RMS ($p = 0.11$) and both groups showed a difference during post-intervention in AP RMS ($p = 0.02$) for EC+NMC$^{\#1}$ compared to EC+NMC +F$^{\#4}$. Individuals in both groups had less PS during condition 3 with haptic feedback, compared to condition 4 with no manual contact. Comparing solid surface (EC+NMC$^{\#1}$ and EC+HF$^{\#2}$) with foam surface conditions (EC+HF+F$^{\#3}$ and EC+NMC+F$^{\#4}$), participants consistently presented less PS during EC+NMC$^{\#1}$ and EC+HF$^{\#2}$ over Baseline and Treatment phases. After Treatment phase, only EXP showed improved PS during EC+NMC+F$^{\#4}$ ($p = 0.01$;$d = 0.39^{S}$) and a tendency during EC+NMC$^{\#1}$ ($p = 0.07$; $d = 0.33^{S}$).

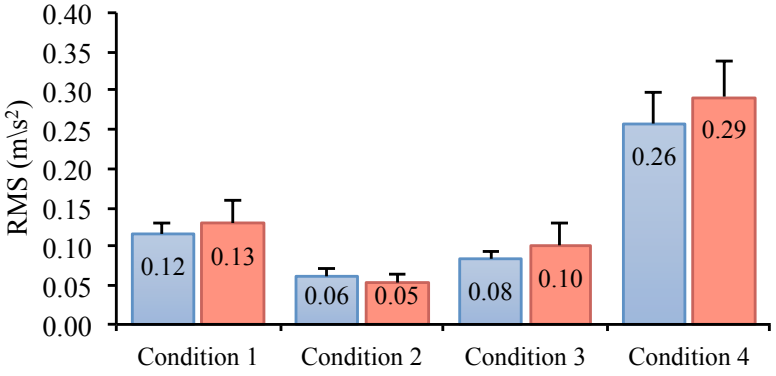


Figure 5.3: Overall Root Mean Square values for EXP and PBO at baseline (mean and SEM).

5.4.2.2 Balance Confidence

Figure 5.6 shows that both EXP ($p = 0.45$; $d = 0.17^{S}$) and PBO ($p = 0.45$; $d = 0.16^{S}$) had similar effects over Baseline phase, each maintaining their scores, with a slight 3% increase. Over the Treatment phase, EXP ($p = 0.07$; $d = 0.35^{S}$) improved slightly by 5% and PBO ($p = 0.44$; $d = 0.19^{S}$) declined by 3%. There were no group differences for baseline ($p = 0.71$; $d = 0.12^{S}$) or pre-intervention ($p=0.79$; $d = 0.11^{N}$) with groups showing 2% difference. There

Table 5.3: Statistical (p-values) and practical (d) significance for overall Root Mean Square between different sensory conditions in both groups from baseline to post-intervention.

	Placebo (n = 13)				Experimental (n = 24)				
	C1	C2	C3	C4	C1	C2	C3	C4	Group difference
Baseline^									
C1	–	0.001	0.01	0.001	–	0.001	0.002	0.001	0.70^{NS}
	–	(1.38^{VL})	(1.01^{L})	(1.39^{VL})	–	(0.72^{M})	(0.34^{S})	(0.84^{L})	(0.08^{N})
C2	0.001	–	0.006	0.001	0.001	–	0.001	0.001	0.16^{NS}
	(1.38^{VL})	–	(0.59^{M})	(2.03^{H})	(0.72^{M})	–	(0.47^{M})	(1.46^{H})	(0.19^{S})
C3	0.01	0.006	–	0.001	0.002	0.001	–	0.001	0.86^{NS}
	(1.01^{L})	(0.59^{M})	–	(1.86^{H})	(0.34^{S})	(0.47^{M})	–	(1.02^{L})	(0.18^{S})
C4	0.001	0.001	0.001	–	0.001	0.001	0.001	–	0.99^{NS}
	(1.39^{VL})	(2.03^{H})	(1.86^{H})	–	(0.84^{L})	(1.46^{H})	(1.02^{L})	–	(0.15^{S})
Pre-intervention									
C1	–	0.001	0.006	0.001	–	0.001	0.001	0.001	0.90^{NS}
	–	(2.06^{H})	(0.49^{M})	(1.78^{H})	–	(0.59^{M})	(0.47^{M})	(0.54^{M})	(0.18^{S})
C2	0.001	–	0.001	0.001	0.001	–	0.001	0.001	0.85^{NS}
	(2.06^{H})	–	(0.69^{M})	(2.82^{H})	(0.59^{M})	–	(0.36^{S})	(1.21^{VL})	(0.17^{S})
C3	0.006	0.001	–	0.001	0.001	0.001	–	0.001	0.98^{NS}
	(0.49^{M})	(0.69^{M})	–	(1.84^{H})	(0.47^{M})	(0.36^{S})	–	(1.13^{VL})	(0.18^{S})
C4	0.001	0.001	0.001	–	0.001	0.001	0.001	–	0.76^{NS}
	(1.78^{H})	(2.82^{H})	(1.84^{H})	–	(0.54^{M})	(1.21^{VL})	(1.13^{VL})	–	(0.10^{N})
Post-intervention									
C1	–	0.001	0.11^{NS}	0.001	–	0.001	0.13^{NS}	0.001	0.60^{NS}
	–	(1.32^{VL})	(0.14^{M})	(1.91^{H})	–	(1.24^{VL})	(0.00^{N})	(1.29^{VL})	(0.01^{N})
C2	0.001	–	0.001	0.001	0.001	–	0.001	0.001	0.60^{NS}
	(1.32^{VL})	–	(1.18^{VL})	(3.27^{H})	(1.24^{VL})	–	(0.76^{L})	(2.08^{H})	(0.34^{S})
C3	0.11^{NS}	0.001	–	0.001	0.13^{NS}	0.001	–	0.001	0.80^{NS}
	(0.14^{M})	(1.18^{VL})	–	(2.47^{H})	(0.00^{N})	(0.76^{L})	–	(1.07^{L})	(0.00^{N})
C4	0.001	0.001	0.001	–	0.001	0.001	0.001	–	0.24^{NS}
	(1.91^{H})	(3.27^{H})	(2.47^{H})	–	(1.29^{VL})	(2.08^{H})	(1.07^{L})	–	(0.55^{M})

Abbreviations: C: Condition; ES: Effect Size; H: Huge effect; L: Large effect; M: Medium effect; N: Negligible effect; NS: Not Significant; VL: Very Large effect. ^Baseline: n = 12 for PBO group. All data was log-transformed. All data was statistically significant except for values marked NS.

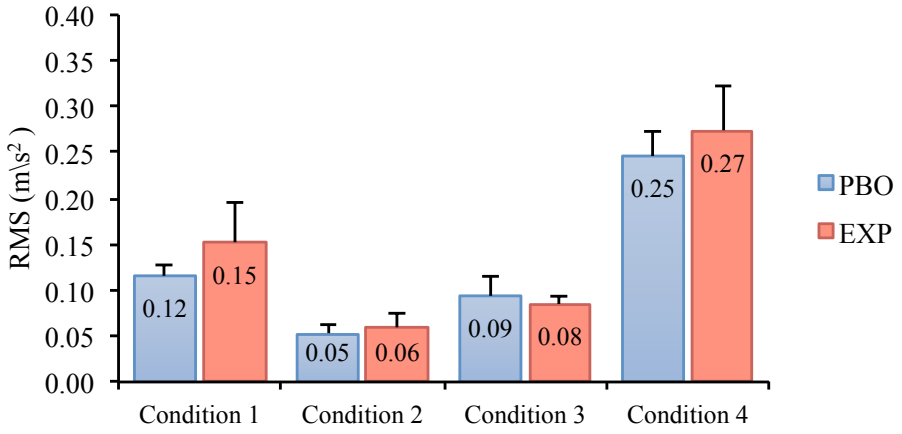


Figure 5.4: Overall Root Mean Square values for EXP and PBO at pre-intervention (mean and SEM).

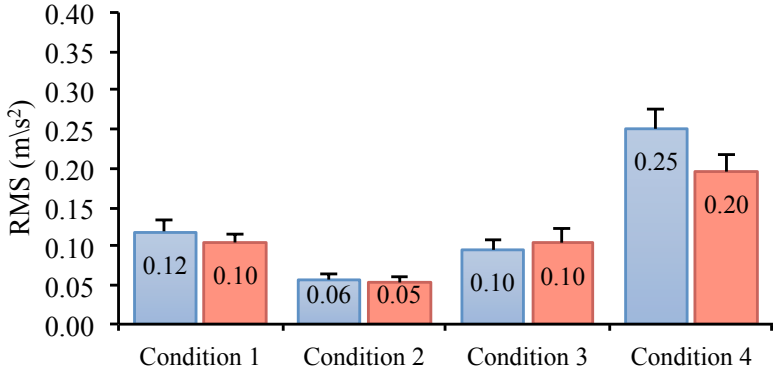


Figure 5.5: Overall Root Mean Square values for EXP and PBO at post-intervention (mean and SEM).

was however a tendency for a group difference post-intervention ($p = 0.07$; $d = 0.74^{M}$), with EXP showing a better score of 10%, compared to the PBO group (Figure 5.6).

5.4.2.3 Motor Experiences of Daily Living

There was no group difference during the Baseline or the Treatment phase ($p > 0.05$). During the Baseline phase EXP presented with 2% improvement ($p = 0.95$; $d = 0.06^{N}$) and PBO with 13% deterioration ($p = 0.20$; $d = 0.18^{S}$) for part II. After the Treatment phase the EXP showed 11% improvement ($p = 0.05$; $d = 0.26^{S}$) and PBO 3% improvement ($p = 0.75$; $d = 0.04^{N}$) during

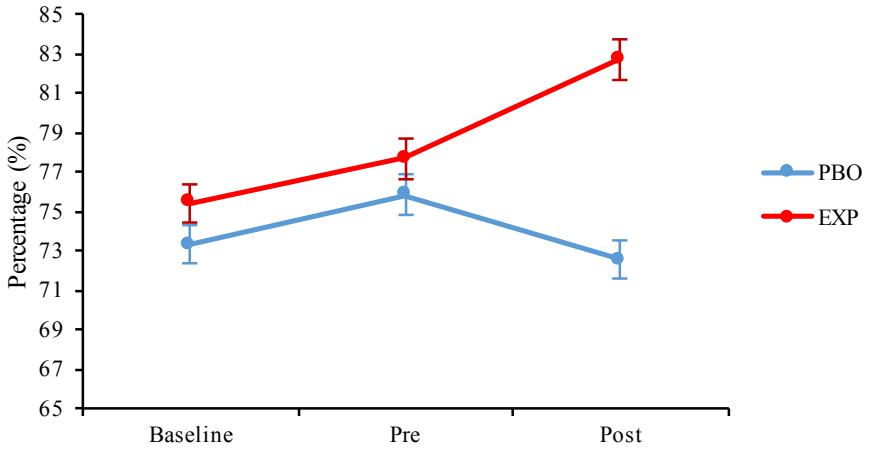


Figure 5.6: Balance confidence scores in EXP and PBO during Baseline and Treatment phases (mean and SEM).

part II (Figure 5.7).

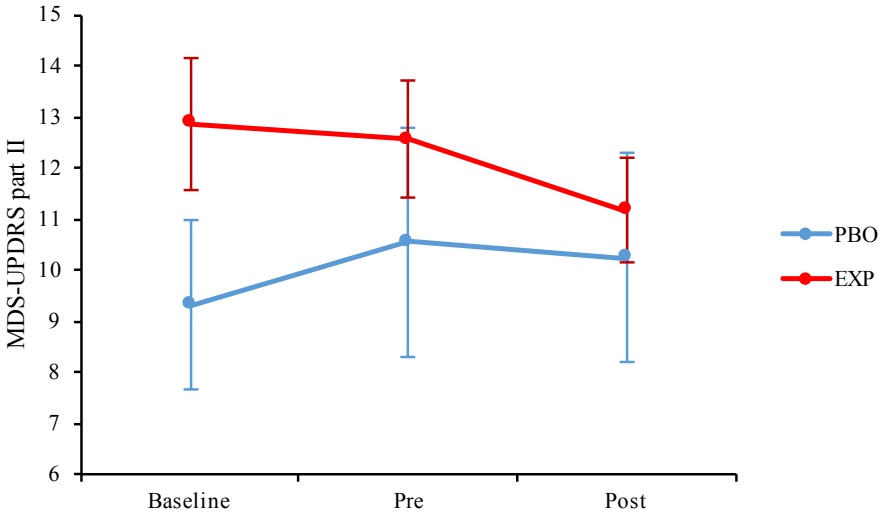


Figure 5.7: Motor experiences of daily living in EXP and PBO during Baseline and Treatment phases (mean and SEM).

5.5 Discussion

To the researcher's knowledge, this is the first investigation that attempted to determine whether a SSTP can alter the haptic feedback influence on PS in individuals with PD. The main results show that eight-weeks of somatosensory training enhances sensory integration. Furthermore, the results support previous research that proprioceptive sensation from light haptic feedback improves PS in PD [180, 92].

Postural sway was measured with RMS, which gives an indication of the amplitude of PS movements, or sway area [10]. Both groups showed lower amplitude of PS when lightly touching a stable reference, when standing on a stable or distorted surface area. Since no intergroup differences were observed, there is no indication that the SSTP can alter haptic feedback influence on PS. Research is very vague on whether haptic feedback is trainable in individuals with balance disorders. Nevertheless, similar to previous studies [180, 92], this study's results show that individuals with PD are able to use the somatosensory information provided by light haptic feedback to reduce their PS. Thus, haptic feedback could be an effective strategy to improve PC during upright standing, and should be implemented during intervention programs for individuals with increased PS [160].

While the SSTP did not alter haptic feedback ability, it did improve sensory integration and had a tendency to improve proprioception in individuals with PD. Participants showed improved sway amplitude during condition 4 where they had only vestibular cues as reliable feedback. Leading to the conclusion that individuals could either rely better on correct vestibular cues or that they could override faulty proprioceptive cues better [148].

Furthermore, EXP showed a tendency for improved balance confidence and motor experiences of daily living after the SSTP. According to Mak and colleagues [181], reduced balance confidence can predict fear of falling in individuals with PD. Researchers stated that a score $<69\%$ on the ABC scale increases risk for sustaining recurrent falls over a 12-month period. This could lead to depression, social isolation and reduced QoL, but since balance confidence is modifiable, interventions such as a SSTP could improve fear of falling as well as motor experiences of daily living to prevent these complications.

Study limitations

Most studies investigated the effect of light haptic feedback with the force application threshold set at 1-2 N [160], because studies have reported that a force greater than 4 N could provide some mechanical support in addition to the somatosensory information [182]. The results were similar to Rabin and

colleagues [92], showing that individuals with PD benefit from sensory information received from light haptic feedback that is independent of mechanical contact (e.g. cane or walking stick) with regards to PC. Thus, the contact forces exerted on the scale by the fingers during this current study was set at a threshold value of 10 N, mainly because individuals with balance problems apply more force than healthy individuals during light touch for haptic feedback [183] and considering that our preliminary study still showed a significant difference between heavy touch and light haptic feedback conditions with a 10 N threshold. Unfortunately, researchers could not report the amount of force applied by the participants on the scale.

This was a non-randomised sample of convenience, and a relatively small sample size was recruited, thus future studies should focus on executing a randomised controlled trial with a larger sample size. The current study made use of an inertial sensor to assess participants' changes in their centre of mass, whereas other investigations on haptic feedback and PD [180, 92] used a forceplate; consequently, limiting the direct transfer of findings between studies.

One of these drawbacks is that no system has been put in place with regards to how ISway measures could be translated into outcomes that can be clinically understood. Lastly, future studies should monitor the amount of haptic feedback that is used during the sensory balance tasks. This will enable researchers to establish whether there is a difference in how much haptic feedback force is used and what the cut-off point is when transitioning from light haptic feedback to mechanical support for individuals with PD specifically.

Conclusion

In summary, we can conclude that the SSTP did not alter the ability to use haptic feedback in individuals with PD, but that the program does have the potential to improve balance confidence and motor experiences of daily living in individuals with PD. Moreover, light haptic feedback does improve PS, regardless of the surface area, and thus cutaneous cues from the fingertips and proprioceptive arm inputs are important in providing sensory information, reducing PS [93]. Physical therapists should develop more balance training activities that utilise haptic feedback, especially for individuals that present with increased PS.

Chapter 6

General Discussion and Conclusion

The present study investigated the effect of a somatosensory training program (SSTP) on postural control (PC) in independent-living individuals with Parkinson's disease (PD). The research hypothesis was that combining balance training exercises with somatosensory feedback as well as manipulating sensory contexts may improve PC through non-dopaminergic pathways. The main findings of the study showed that sensory integration, mobility and functional balance, PD motor severity, perceived Quality of Life (QoL) and concern for falling can be improved by a SSTP. In addition the investigation confirmed that haptic feedback improved postural sway (PS) in all participants, even though the SSTP did not specifically enhance haptic feedback.

6.1 Baseline Characteristics

No differences were found in demographic data between the experimental (EXP) and placebo (PBO) groups. However, there were some group differences in balance performance during the Baseline phase, which will be discussed subsequently in this chapter.

Of the 37 individuals that participated in the study, 23 were male, whereas only 14 were female. According to previous research, men have a higher prevalence of PD compared to women [184, 185], and epidemiological studies showed the male sex to be an important risk factor for developing PD at any age and nationality [186]. A large meta-analysis study suggested that two times more men suffer from PD compared to woman, in any specific time frame [187]. The interaction of genetic, hormonal, environmental and lifestyle factors has shown to have a big influence on the dopaminergic system. Authors found that the Y-chromosome gene, also known as sex-determining region Y (SRY) protein responsible for initiation of male sex determination in humans, directly influences the dopamine system and thus contributes to the greater susceptibility to PD seen in males [186]. Furthermore, intriguing evidence suggests

that testicular steroids increase neurodegeneration of the dopamine system, while estrogens have a neuroprotective effect against dopaminergic loss [188]. Finally, agrichemicals and head injuries have been linked to an increased risk for men to develop PD, due to occupational exposure [189] and an increased probability of traumatic brain injures due to contact sports [190]. In this current study men could be somewhat over-represented, which raises the question whether men and woman respond differently to training. However, research is vague on whether gender plays a specific role in balance training. Thus, it is important that future research focus on reflecting the general PD population with regard to gender in order to support the generalisability of findings [132].

Individuals diagnosed with PD range between $20 - 80$ years old, and research suggests that the average age of PD motor symptoms and diagnosis is around 60 years old [169, 170]. With regard to this study, the average age was 69 (SD 9) years and according to the American Geriatrics Society this age group is at increased risk for falls. Physical activity levels drop with aging causing functional decline, and individuals with PD terminate physical activity earlier that healthy controls, leading to reduced QoL. Exercise is defined as planned, structured physical activity, which aims to improve or maintain one or more aspects of physical fitness [191]. Physical activity status was noted before the intervention started to measure the baseline status of each participant. No changes in their physical activity status were allowed after the Baseline phase, thus the exercises participated in during this phase were the only physical activities the individuals were allowed to continue doing during the Treatment phase. It is very important to remain physically active as it has been shown to improve physical functioning as well as health related QoL in individuals with PD [132, 114].

Body composition can be measured by Body Mass Index (BMI), which is based on weight in relation to height, and applies to most adult individuals over the age of 20 years. A BMI of ≥ 25 is classified as overweight while a BMI of ≥ 30 is classified as obese [191]. Participants in both groups had similar BMI's of about 28 (SD 5) on average. This places both groups in the overweight category, borderline obese. Balance instability is a key indicator of falls, and research shows that a higher body weight represents increased balance instability [192]. Furthermore, Greve et al. [193] showed that there is a positive correlation between BMI and increased postural instability, confirming that excess weight causes greater unsteadiness. Thus, it is very important that these individuals receive balance-specific treatment to reduce fall risk [194].

The Hoehn and Yahr (H&Y) staging is the most frequently used global assessment for individuals with PD [6, 195]. This scale is based on physical impairment and balance dysfunction, but does not provide sufficient information on some motor features. Martínez-Martín and colleagues [7] recently

proposed that more detailed assessments, as the Movement Disorder Society-Unified Parkinson's Disease Rating Scale (MDS-UPDRS), be used to classify the severity levels of individuals with PD together with the H&Y scale. The current study focused on individuals with mild to moderate PD, defined as stage 1-3 on the H&Y scale as well as a MDS-UPDRS part III (motor examination) score of less than 59. Both groups were in the stage 2 category of the H&Y, which is defined as bilateral disease, without impairment of balance [6]. Additionally, individuals had to live an independent lifestyle which was defined in Chapter 2, as someone who takes control of their life and choose how that life should be led [5]. There was no significant difference between EXP and PBO in terms on the H&Y scale, but a tendency for difference was seen in the part III of the MDS-UPDRS. The PBO participants presented with a lower disease severity score compared to EXP, which will be taken into account in the following sections of this discussion chapter. It should also be taken note of that there were more individuals in the EXP group, which might play a role in this finding, as this produced a greater variety in the group.

In terms of global cognitive function, both groups showed similar mild cognitive impairment. Overall participants had either no or mild cognitive impairment, thus researchers assume that individuals understood the tests performed and could execute it with confidence. This was a prerequisite for participating in the study because the focus was on PC and not on cognitive functioning. Furthermore, it is known that individuals with mild cognitive impairment are at increased risk for falls and mobility decline, making them a vulnerable population [196].

Individuals were tested on medication at the same place as well as in the same sequence and by the same assessor. This was done to maintain consistency during testing in the Baseline and Treatment phase, as well as to try and minimise the effects of dopaminergic medication. Research has shown that dopaminergic medication improves discreet balance perturbations but not overall stability, because non-dopaminergic PC pathways might exist [23], or because some medication reduce muscle tone and therefore degrade balance [99]. Furthermore, haptic feedback was shown to be equally beneficial regardless of the participant being off or on medication since the effect of medication on PS was not significant [92]. Therefore, we assume that this variable did not have an influence on our results.

Even though there were no demographic differences between EXP and PBO, there were balance performance differences between the groups at baseline, which should be considered when interpreting the results. Firstly, there was a significant group difference in jerkiness (JERK) and Centroidal Frequency (CF) during the modified Clinical Test of Sensory Interaction and Balance (mCTSIB) condition where participants had to stand with eyes open

on the foam, as well as for MDS-UPDRS part III. Initially it was thought that the two variables could have had an influence on each other, but an indirect relationship was found. The PBO presented with more jerkiness and frequency of sway during this sensory balance task, whereas their MDS-UPDRS part III score was lower compared to EXP. Thus, disease severity had no effect on this sensory balance task and researchers can only conclude that the PBO group was either more proprioceptive dependent than the EXP group or that the PBO group did not effectively use the visual information available to them to maintain their balance. Unfortunately, the groups did not have equal amount of participants in each group, and this was a sample of convenience study, which could contribute to above mentioned results.

Intragroup differences from baseline to pre-intervention were also marked in both groups. The PBO group improved in the Parkinson's Disease Quality of Life Questionnaire Summary Index (PDQ-39 SI) after the Baseline phase. The two groups followed a time-series design, however the baseline testing of each group was staggered. This was done for practical reasons to collect data form the two groups. The pre-intervention testing occurred before the summer holidays for the EXP and after the holidays for the PBO. The specific time of year, for PBO Baseline phase, is known as a time spent with family and friends. Hence the timeline could have influenced the perceived state of the PBO participants and might have manifested in a perceived increase in QoL.

Furthermore, the EXP improved in the Timed-Up-and-Go (TUG) during the Baseline phase more so than the PBO. One may argue that there could have been a learning effect in the TUG, and that individuals were more motivated in EXP after the Baseline phase and ready to commence with the Treatment phase. Furthermore, the duration of the TUG has been shown to correlate well with severity of moderate-to-severe PD [197], but is not sensitive to individuals with early PD severity level [198]. The EXP group had an average H&Y stage of 2 (SD 1), which places them in the mild-to-moderate PD category. Thus, the combination of the early-to-moderate PD level with the motivated mind state to begin the SSTP could have led to an improvement during Baseline phase.

6.2 Systems Framework for Postural Control

As mentioned earlier in Chapter 2, an intact PC system is important for stability as well as for accomplishing activities of daily living safely [57]. Individuals with PD present with impaired mobility because of locomotor and balance dysfunction [54]. According to the Systems Framework for Postural Control [27], there are six domains that are essential for PC, and disturbances in one or more of these domains could be the source of postural instability. Chapter

2 presented how the ailments of PD affect study-related domains of the PC system. Thus for the purpose of this discussion, the effect of a SSTP on four domains of the PC system will be discussed, namely Biomechanical Constraints, Sensory Strategies, Orientation in Space and Control of Dynamics.

6.2.1 Biomechanical Constraints

Balance is severely affected by any changes in the base of support [27] as well as by any limitations in the size, strength, range, pain or control of the feet [199]. Individuals suffering from PD have an abnormal smaller cone of stability representation, leading to postural instability [27, 71]. During all the sensory balance tasks, individuals had to stand in a modified tandem stance which created a smaller base of support, and consequently reduced the individual's stability. When researchers observed the simplest balance task in this study, eyes open in a tandem stance, the EXP individuals presented with significantly less frequency of sway after the Treatment phase. Thus, the SSTP helped individuals to control the speed (CF) of their sway better, leading to increased stability. Furthermore, not only did EXP improve from before the Treatment phase to after the Treatment phase, but there was also a group difference after the Treatment phase with the PBO showing significantly worse frequency of sway compared to EXP. According to Stylianou et al [72] reduced PC leads to an increase in postural instability, thus we can believe that an increase in postural stability would increase PC, resulting in higher QoL and life expectancy because of a reduced risk of falling, soft tissue injuries, fractures and psychological fear of falling.

Unfortunately, limits of stability was not assessed directly, yet it would be interesting and worthwhile to see whether a SSTP could improve the internal representation, since it is known that individuals with PD have difficulty with this aspect due to poor proprioception. The SSTP included several exercises that focussed on improving internal representation, for example individuals executed trunk leans in different directions, reaching for objects, and did both these exercises in normal and tandem stance as well as under different sensory conditions. Sensory integration of the proprioceptive, vestibular and visual system are all involved in the development of an internal representation because body posture continuously has to be updated and adapted to control body position [200, 201]. Since sensory integration improved in the EXP group researchers predict that the EXP groups' internal representations would have improved, but more research should be done to confirm this prediction.

6.2.2 Sensory Strategies

The ability to maintain balance during quiet standing, regardless of the base of support, depends greatly on the interaction of the visual, vestibular and

somatosensory system [54]. Different sensory balance tasks were given to the participants, which forced the individual to adapt to a changing environment and to constantly shift their sensory weight between different conditions. Since individuals with PD struggle with sensory reweighting [74], researchers expected participants to show reduced PC, with an associate increase in PS, during conditions where they have to stand on an unstable surface with their eyes closed. The EXP and PBO participants presented with very high postural sway values, during the sensory condition described above, compared to other sensory balance tasks before the intervention started. However, a treatment effect was found for sway jerkiness during this condition, the EXP group presented with less sway jerkiness, frequency and amplitude after the SSTP and EXP presented with significantly less jerkiness compared to PBO after the Treatment phase. Additionally, PBO showed significantly more frequency of sway after the Treatment phase, confirming that the wristband had no effect on sensory integration. During this condition, somatosensory as well as visual input was altered, and according to Haran et al. [73], if sensory input is absent or inappropriate for the given context, then other more reliable sensory input will provide the principal information to maintain balance, which was vestibular information in this case. Previous research states that this phenomenon cannot necessarily be attributed to difficulty with vestibular information use, but to the inability to shift between sensory systems [75, 76]. However, more recent research states that the vestibular system is a principal proprioceptor, which helps monitor one's own capability to maintain balance [29]. Thus, researchers concluded that the SSTP: 1) improved an individual's ability to shift their sensory control between the visual, vestibular and somatosensory system; 2) helped the individuals to override faulty proprioceptive feedback and rather focus on reliable vestibular cues to maintain PC; and 3) has the potential to improve an individual's ability to integrate sensory information and thus enable individuals to utilise more of the sensory information available.

Previous research has indicated that individuals with PD have impaired proprioception [78], causing them to rely predominantly on visual information for postural stability. But with aging the visual system becomes impaired, leading to reliance on impaired proprioceptive information [80]. Results from this study support previous findings that PD individuals are visual dependent [164, 75, 77, 133, 80, 165], and therefore it is crucial to implement strategies to improve proprioception in individuals with PD.

6.2.3 Orientation in Space

Parkinson's disease individuals present with several subjective sensory symptoms (numbness, coldness etc.) as well as somatosensory deficits, including inadequate proprioception [31, 79] and poor haptic feedback [42].

Proprioception is an integral component in the sensory part of sensory-motor interaction, which allows one to maintain an unsteady equilibrium while the muscles work against gravity. Furthermore, joint position sense (JPS) is known as a form of proprioception, and is described as the ability to perceive the position of the joint (e.g. ankle) in the absence of vision. The Active Movement Extent Discrimination Apparatus (AMEDA) was used to assess JPS in individuals with PD. Proprioception is an important factor in the protection and performance of ankle control, thus ankle proprioception was assessed [202]. This was the first study done on individuals with PD using the AMEDA protocol, and was based on a previous study investigating the effect of a five-week wobble-board exercise intervention on JPS in healthy elderly individuals. Results from the current study showed that the EXP significant improved absolute error scores in JPS after the Treatment phase. However, PBO showed the same practical improvement as EXP, except improvements were not significant. Previous research investigated the effect of somatosensory stimulation, by means of Whole-Body Vibration (WBV), but found no positive results [112, 113]. Thus there is a big gap in research in terms of proprioceptive testing as well as on individuals with PD.

Haptic feedback is impaired in individuals with PD [42], yet it has been suggested that the light touch provides sensory feedback about body orientation which is sufficient in improving static PC [93, 94, 92]. The study results confirmed that haptic feedback provides sensory feedback about body orientation and successfully reduces PS. Very little research regarding haptic feedback and its influence on PC has been done. The more research is done with this regard, the better solutions can be found to improve postural instability in PD individuals. Using haptic feedback in rehabilitation may be a simple and cost-effective way to improve PC. Thus clinicians should utilise this information to educate patients about the potential positive effects of haptic feedback on PC, regardless of the surface area they walk on. Additionally research is very vague on whether haptic feedback can be trained in individuals with balance disorders. Results confirmed that haptic feedback (< 10 N) cannot be trained through a SSTP, but further research is wanted. A possible reason for this occurrence might be that the environment was not controlled enough to induce improvement in haptic feedback, and that is should be monitored more closely. In the SSTP haptic feedback was induced through lightly touching a chair, wall or a partners hands during static and dynamic balance tasks. The force applied was not assessed, however previous researchers [175] have shown that "free touch" is typically 10 times that of light touch (< 1 N). Exercises were done with manipulated visual and vestibular input as well as with alterations in their base of support.

6.2.4 Control of Dynamics

As mentioned before, individuals with PD have impaired sensory integration, which amplifies the deficits they experience with PC [91]. These deficits form the foundation of postural instability leading to a reduced ability to control the centre of mass within the base of support during mobility and can eventually manifest themselves in falls [100]. The TUG is often used to test general mobility skills in elderly population as well as individuals who have neurological conditions [203]. Besides mobility, the TUG assesses lower extremity function and strength, coordination, balance and fall risk [204, 205]. This mobility test includes different components such as sit-to-stand, walking 3 m forward, turning, walking back to the chair, and stand-to-sit [206]. The components sit-to-stand, turning and stand-to-sit can be described as postural transitions, which seem to be affected in individuals with PD [207]. The PBO participants did not show any significant changes over the testing period, but did present with a worse time, whereas the EXP group significantly improved from pre- to post-intervention. Since the EXP group improved during the Baseline phase as well, results should be interpreted conservatively. Fortunately, there was a treatment effect for the TUG as well as a group difference after the Treatment phase, which possibly supports the finding that SSTP improved mobility and functional balance in individuals with PD.

The differences between the two groups after the Treatment phases resulted in the EXP group being closer to the non-fallers category and the PBO group closer to the fallers category [100]. Schenkman et al. [208] established norms for the TUG in individuals with PD with regards to their disease severity (H&Y). The TUG times of both groups were above 10.89 sec during baseline, which according to above mentioned norms, placed them between stage III and stage IV on the H&Y scale. During pre-intervention the PBO stayed in this high severity stage, while the EXP moved slightly below the stage III on the H&Y scale. After the Treatment phase, the PBO group increased even more in their severity stage, whereas EXP could be classified between stage I and stage II on the H&Y scale [208]. Thus not only does the SSTP directly improve mobility and functional balance, but it also indirectly reduces fall risk as well as disease severity in individuals with PD.

6.3 Perceived Health and Balance Related Measures

This section was assessed by means of questionnaires which focused on the "perception and evaluation by patients themselves of the impact that illness and its consequences have in their life" [209]. The EXP group showed a strong tendency for improved QoL after the Treatment phase and indicated enhanced

perceived QoL from pre- to post-intervention. The PDQ-39 SI is used to evaluate the overall effect of different interventions, assessing an individual's functionality as well as well-being, and what the impact of the illness is on these factors [145]. The SSTP might have improved walking capability as well as the ability to adapt to certain task requirements, which are all important when addressing mobility issues seen in PD. The last three weeks of the SSTP consisted of functional activities, which focused on task and context specific activities that are essential and of meaning to the participants, as well as promoting functional independence. Other factors that also play a big role in performing activities of daily living and resembling improved QoL is fear of falling and balance confidence.

The Fall-Efficacy Scale International (FES-I) was used to assess concern for falling in individuals with PD and a significant treatment effect was observed in the EXP group after the SSTP. Balance confidence was assessed by means of the Activity-specific Balance Confidence scale (ABC) and showed a similar trend as in concern for falling. Both EXP and PBO had similar opinions with regard to fear of falling and their balance confidence before the intervention started. However, after the Treatment phase the PBO groups' perceptions of concern for falling and confidence to maintain balance during activities of daily living deteriorated, whereas contrarily EXP showed improved concern for falling and balance confidence viewpoints. Both the FES-I and ABC has been said to assess fear of falling during everyday tasks and cut-off values have been set at > 30 for the FES-I and $\leq 46\%$ for the ABC for individuals with PD [210]. According to Almeida and colleagues [210], the FES-I has a higher sensitivity for fear of falling, but that both questionnaires resemble similar values. This is confirmed by our results as the same trend was seen in both PBO and EXP before and after the intervention. Albeit not statistically significant changes in EXP from pre- to post-intervention, concern for falling and balance confidence showed noteworthy practical difference after the Treatment phase.

The last questionnaire that was used was the MDS-UPDRS. Researchers examined motor experiences of daily living (part II), motor functionality (part III) in participants as well as looked at the overall burden and extent of PD, taking motor as well as non-motor experiences of daily living, severity and motor complications into consideration [129]. Even though there are no cut-off values available, normative data has been established for part II (16.0 ± 10), part III (36.8 ± 18.4) and total score (68.4 ± 32.8) for the MDS-UPDRS in individuals with PD [129]. Both groups in this study always scored lower than the normative data. During all three graphs the PBO group scored lower than the EXP group, indicating that they had better non-motor experiences of daily living, motor functionality as well as a better overall disease severity state. However, as PD is a progressive neurological disorder, the PBO group might have had better scores at the beginning of the 16-weeks, but they

progressively worsened until they had very similar scores to that of the EXP group. In contrast, the EXP group might not have significantly improved their scores after the Treatment phase, but they successfully maintained their non-motor experiences of daily living, motor functionality as well as a better overall disease severity state. Even more, when looking at the total score of the MDS-UPDRS, a cross over occurred during post-intervention where the PBO group scored worse than the EXP group after the Treatment phase (Figure 4.4). Once again a significant treatment effect was observed in both part III and total score of the MDS-UPDRS for EXP. These findings just reinforce the impression that the SSTP was effective in improving functionality and well-being in individuals with PD. Researchers conclude that somatosensory exercise efficiently improves the perception of patients regarding the impact and consequences of PD on their lives as defined by Martínez-Martín and colleagues [209].

6.4 Study Limitations and Future Studies

Limitations are an imperative and unpreventable part of any scientific research study. It highlights the conditions and circumstances that may influence or limit the outcome of the study. The development and application of the SSTP revealed the following limitations and recommendations for future studies are also incorporated.

- Study design – The current study used a time-series experimental study with a sample of convenience. This is known as one of the strongest quasi-experimental study designs and was chosen because logistically it was the best fit for the type of population researchers used. Originally a randomised control trial was submitted - however after performing a pilot study to calculate the sample size it was seen that it would not be a practical or viable option because the individuals lived so far apart.

- Sample characteristics – Volunteer participants were a sample of convenience recruited through responses to advertisement in newsletters in PD support groups as well as local newspapers. The sample size was relatively small, unequal in numbers and consisted of more male participants than female. Thus results might not be generalised to the whole PD population and some of these factors could have created bias which should be taken into consideration when further research regarding this topic is attempted. Furthermore, the PBO group was slightly older, although nothing statistically significant, which could be considered as a possible influence and should be seen as a confounding variable.

- Testing equipment – The Instrumented Sway (ISway) was used to assess PC, because researchers did not have access to a force plate which is

the golden standard for PC assessment. The ISway has been proven to be an inexpensive and efficient alternative for measuring PS, however a system should still be put in place with regards to translating how the outcome measures could be clinically relevant as well as which sway measure is most appropriate for assessing balance [10]. Joint position sense was measured using the AMEDA and this was the first study to do so on individuals with PD. Proprioception is very difficult to assess [112], and future studies should focus on finding effective ways to measure proprioception and apply that knowledge to movement disorders affected by impaired proprioception.

- Disease severity classification – It should be noted that there is a slight difference between the subjective rating of the H&Y stages in comparison with the TUG norms for H&Y disease severity. The current study combined the H&Y scale with the MDS-UPDRS part III to define disease severity, however future research might find it beneficial to combine the H&Y and TUG norms [208] to assess severity level of participants. There is still uncertainty on how to classify the disease state of individuals with PD effectively, thus more research is needed for clarification.

- Medication – Individuals were tested on medication, thus future research should endeavour to test individuals off medication as well, to minimise the effect of dopaminergic medication. Another alternative could be to measure medication level before each assessment, to be assured that the medication effects on balance performance is consistent. With regards to haptic feedback assessments, Rabin et al. [92] uncovered that medication and using affected or non-affected side has no significant effect on PS while using haptic feedback in individuals with PD. Thus, haptic feedback is equally beneficial regardless of the participant being on or off medication and therefore we assume that this uncontrolled variable did not have an influence on our results.

In terms of other recommendations for future studies it could be interesting to see whether a shorter intervention might also have an effect on PC in individuals with PD. Also, whether there is a difference between individual sessions compared to group sessions. Lastly, whether a SSTP could be effective as a home program even though it would be without therapist supervision.

6.5 Conclusion

Somatosensory training may be a cost-effective and simple way to improve PC in individuals with PD. This training method requires little equipment and it can be executed in a group setting, which facilitates social interaction. Very little research regarding somatosensory training and the influence thereof

on PC has been done. Parkinson's disease is placing a very high burden on health care systems worldwide as the populations life-expectancy is increasing in several countries [186]. It is therefore crucial to find cost-effective solutions on how to improve the QoL, mobility and improve sensory-motor interaction in individuals with PD. The results of this study should hence be used to create activities or other solutions to help individuals with PD to regain or maintain PC.

List of References

[1] Jacobson GP. Handbook of balance function testing. Mosby Elsevier Health Science; 1993.

[2] Nashner L, Larry R. Balance and posture control. Encyclopedia of Neuroscience. 2009;p. 21–29.

[3] Mancini M, Horak FB, Zampieri C, Carlson-Kuhta P, Nutt JG, Chiari L. Trunk accelerometry reveals postural instability in untreated Parkinson's disease. Parkinsonism & related disorders. 2011;17(7):557–562.

[4] O'Malley MK, Gupta A. In: Haptic Interfaces. Morgan-Kaufman Publisher; 2008. p. 25–74.

[5] Brisenden S. Independent living and the medical model of disability. Disability, Handicap & Society. 1986;1(2):173–178.

[6] Hoehn MM, Yahr MD. Parkinsonism: onset, progression, and mortality. Neurology. 1967;17(5):427–442.

[7] Martínez-Martín P, Rodríguez-Blázquez C, Alvarez M, Arakaki T, Arillo VC, Chaná P, et al. Parkinson's disease severity levels and MDS-Unified Parkinson's Disease Rating Scale. Parkinsonism & related disorders. 2015;21(1):50–54.

[8] Shumway-Cook A, Woollacott MH. Motor control: translating research into clinical practice. Lippincott Williams & Wilkins; 2007.

[9] Fredericks CM, Saladin LK, Fredericks C. Pathophysiology of the motor systems: principles and clinical presentations. FA Davis Philadelphia, PA; 1996.

[10] Mancini M, Salarian A, Carlson-Kuhta P, Zampieri C, King L, Chiari L, et al. ISway: a sensitive, valid and reliable measure of postural control. J Neuroeng Rehabil. 2012;9(59):59.

[11] Abbruzzese G, Berardelli A. Sensorimotor integration in movement disorders. Movement disorders. 2003;18(3):231–240.

[12] Ayres AJ, Robbins J. Sensory integration and the child: Understanding hidden sensory challenges. Western Psychological Services; 2005.

[13] Kars HC, Hijmans JM, Geertzen JH, Zijlstra W. The effect of reduced somatosensation on standing balance: a systematic review. Journal of diabetes science and technology. 2009;3(4):931–943.

[14] Aman JE, Elangovan N, Yeh IL, Konczak J. The effectiveness of proprioceptive training for improving motor function: a systematic review. Frontiers in human neuroscience. 2014;8.

[15] Obeso JA, Rodríguez-Oroz MC, Benitez-Temino B, Blesa FJ, Guridi J, Marin C, et al. Functional organization of the basal ganglia: therapeutic implications for Parkinson's disease. Movement Disorders. 2008;23(S3):S548–S559.

[16] Sage MD, Almeida QJ. Symptom and gait changes after sensory attention focused exercise vs aerobic training in Parkinson's disease. Movement disorders. 2009;24(8):1132–1138.

[17] Al Masud SMR. Study And Analysis Of Scientific Scopes, Issues And Challenges Towards Developing A Righteous Wireless Body Area Network. International Journal Of Soft Computing And Engineering (IJSCE). 2013;.

[18] Nichols WC, Pankratz N, Hernandez D, Paisán-Ruíz C, Jain S, Halter CA, et al. Genetic screening for a single common LRRK2 mutation in familial Parkinson's disease. The Lancet. 2005;365(9457):410–412.

[19] Blanckenberg J, Bardien S, Glanzmann B, Okubadejo NU, Carr JA. The prevalence and genetics of Parkinson's disease in sub-Saharan Africans. Journal of the neurological sciences. 2013;335(1):22–25.

[20] Velkoff VA, Kowal PR. Population aging in Sub-Saharan Africa: demographic dimensions 2006. vol. 7. US Dept. of Commerce, Economics and Statistics Administration, US Census Bureau; 2007.

[21] Okubadejo NU, Bower JH, Rocca WA, Maraganore DM. Parkinson's disease in Africa: A systematic review of epidemiologic and genetic studies. Movement disorders. 2006;21(12):2150–2156.

[22] Graham D. Worlds apart? Parkinson's in South Africa. EPDA Plus. 2012;.

[23] Bloem BR, Beckley DJ, Van Dijk JG, Zwinderman AH, Remler MP, Roos RA. Influence of dopaminergic medication on automatic postural responses and balance impairment in Parkinson's disease. Movement disorders. 1996;11(5):509–521.

[24] Revilla FJ, Larsh TR, Mani A, Duker AP, Cox C, Succop P, et al. Effect of dopaminergic medication on postural sway in advanced Parkinson's disease. Frontiers in neurology. 2013;4.

[25] Riemann BL, Lephart SM. The sensorimotor system, part I: the physiologic basis of functional joint stability. Journal of athletic training. 2002;37(1):71.

[26] Keysers C, Kaas JH, Gazzola V. Somatosensation in social perception. Nature Reviews Neuroscience. 2010;11(6):417–428.

[27] Horak FB. Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls? Age and ageing. 2006;35(suppl 2):ii7–ii11.

[28] Matthews P. Where does Sherrington's "muscular sense" originate? Muscles, joints, corollary discharges? Annual review of neuroscience. 1982;5(1):189–218.

[29] Pagliano P. Using a multisensory environment: A practical guide for teachers. Routledge; 2013.

[30] King J, Karduna A. Joint position sense during a reaching task improves at targets located closer to the head but is unaffected by instruction. Experimental brain research. 2014;232(3):865–874.

[31] Schneider JS, Diamond SG, Markham CH. Parkinson's disease Sensory and motor problems in arms and hands. Neurology. 1987;37(6):951–951.

[32] Klockgether T, Borutta M, Rapp H, Spieker S, Dichgans J. A defect of kinesthesia in Parkinson's disease. Movement Disorders. 1995;10(4):460–465.

[33] Demirci M, Grill S, McShane L, Hallett M. A mismatch between kinesthetic and visual perception in Parkinson's disease. Annals of neurology. 1997;41(6):781–788.

[34] Zia S, Cody F, O'Boyle D. Joint position sense is impaired by Parkinson's disease. Annals of neurology. 2000;47(2):218–228.

[35] Adamovich S, Berkinblit M, Hening W, Sage J, Poizner H. The interaction of visual and proprioceptive inputs in pointing to actual and remembered targets in Parkinson's disease. Neuroscience. 2001;104(4):1027–1041.

[36] Maschke M, Gomez CM, Tuite PJ, Konczak J. Dysfunction of the basal ganglia, but not the cerebellum, impairs kinaesthesia. Brain. 2003;126(10):2312–2322.

[37] Byblow WD, Lewis GN, Stinear JW. Effector-specific visual information influences kinesthesis and reaction time performance in Parkinson's disease. Journal of motor behavior. 2003;35(2):99–107.

[38] Keijsers N, Admiraal M, Cools A, Bloem B, Gielen C. The accuracy of pointingmove-ments to remembered visual targets in Parkinson's disease. Eur J Neurosci. 2005;21:239–248.

[39] Botden SM, Torab F, Buzink SN, Jakimowicz JJ. The importance of haptic feedback in laparoscopic suturing training and the additive value of virtual reality simulation. Surgical endoscopy. 2008;22(5):1214–1222.

[40] Minogue J, Jones MG. Haptics in education: Exploring an untapped sensory modality. Review of Educational Research. 2006;76(3):317–348.

[41] Hale KS, Stanney KM. Deriving haptic design guidelines from human physiological, psychophysical, and neurological foundations. Computer Graphics and Applications, IEEE. 2004;24(2):33–39.

[42] Salgado S, Williams N, Kotian R, Salgado M. An Evidence-Based Exercise Regimen for Patients with Mild to Moderate Parkinson's Disease. Brain sciences. 2013;3(1):87–100.

[43] Sigrist R, Rauter G, Riener R, Wolf P. Augmented visual, auditory, haptic, and multimodal feedback in motor learning: A review. Psychonomic bulletin & review. 2013;20(1):21–53.

[44] Oakley I, Brewster S, Gray P. Can you feel the force? An investigation of haptic collaboration in shared editors. In: proceedings of EuroHaptics; 2001. p. 54–59.

[45] Bulbulian R, Hargan ML. The effect of activity history and current activity on static and dynamic postural balance in older adults. Physiology & behavior. 2000;70(3):319–325.

[46] Allen NE, Schwarzel AK, Canning CG. Recurrent falls in Parkinson's disease: a systematic review. Parkinson's Disease. 2013;2013.

[47] Canning CG, Sherrington C, Lord SR, Close JC, Heritier S, Heller GZ, et al. Exercise for falls prevention in Parkinson disease A randomized controlled trial. Neurology. 2015;84(3):304–312.

[48] Holmes JD, Jenkins ME, Johnson AM, Hunt MA, Clark RA. Validity of the Nintendo Wii® balance board for the assessment of standing balance in Parkinson's disease. Clinical Rehabilitation. 2013;27(4):361–366.

[49] Latt MD, Lord SR, Morris JG, Fung VS. Clinical and physiological assessments for elucidating falls risk in Parkinson's disease. Movement Disorders. 2009;24(9):1280–1289.

[50] Smania N, Corato E, Tinazzi M, Stanzani C, Fiaschi A, Girardi P, et al. Effect of balance training on postural instability in patients with idiopathic Parkinson's disease. Neurorehabilitation and Neural Repair. 2010;24(9):826–834.

[51] Li F, Harmer P, Fitzgerald K, Eckstrom E, Stock R, Galver J, et al. Tai chi and postural stability in patients with Parkinson's disease. New England Journal of Medicine. 2012;366(6):511–519.

[52] Bloem BR, Grimbergen YA, Cramer M, Willemsen M, Zwinderman AH. Prospective assessment of falls in Parkinson's disease. Journal of neurology. 2001;248(11):950–958.

[53] Pickering RM, Grimbergen YA, Rigney U, Ashburn A, Mazibrada G, Wood B, et al. A meta-analysis of six prospective studies of falling in Parkinson's disease. Movement Disorders. 2007;22(13):1892–1900.

[54] Schoneburg B, Mancini M, Horak F, Nutt JG. Framework for understanding balance dysfunction in Parkinson's disease. Movement Disorders. 2013;28(11):1474–1482.

[55] Guskiewicz KM. Postural stability assessment following concussion: one piece of the puzzle. Clinical Journal of Sport Medicine. 2001;11(3):182–189.

[56] Allen NE, Sherrington C, Paul SS, Canning CG. Balance and falls in Parkinson's disease: A meta-analysis of the effect of exercise and motor training. Movement disorders. 2011;26(9):1605–1615.

[57] Mancini M, Horak FB. The relevance of clinical balance assessment tools to differentiate balance deficits. European journal of physical and rehabilitation medicine. 2010;46(2):239.

[58] Brown LA, Cooper SA, Doan JB, Dickin DC, Whishaw IQ, Pellis SM, et al. Parkinsonian deficits in sensory integration for postural control: temporal response to changes in visual input. Parkinsonism & related disorders. 2006;12(6):376–381.

[59] Horak F, Nutt J, Nashner L. Postural inflexibility in parkinsonian subjects. Journal of the neurological sciences. 1992;111(1):46–58.

[60] Prakash A, Krishnan K. Ageing at system level: neurological ageing. Oxford Textbook of Anaesthesia for the Elderly Patient. 2014;p. 37.

[61] Proske U, Gandevia SC. The proprioceptive senses: their roles in signaling body shape, body position and movement, and muscle force. Physiological reviews. 2012;92(4):1651–1697.

[62] Almeida STd, Soldera CLC, Carli GAd, Gomes I, Resende TdL. Analysis of extrinsic and intrinsic factors that predispose elderly individuals to fall. Revista da Associação Médica Brasileira. 2012;58(4):427–433.

[63] Masud T, Morris RO. Epidemiology, of falls. Age and ageing. 2001;30:3–7.

[64] Kallin K, Lundin-Olsson L, Jensen J, Nyberg L, Gustafson Y. Predisposing and precipitating factors for falls among older people in residential care. Public health. 2002;116(5):263–271.

[65] Gauchard G, Chau N, Mur J, Perrin P. Falls and working individuals: role of extrinsic and intrinsic factors. Ergonomics. 2001;44(14):1330–1339.

[66] Rankin JK, Woollacott MH, Shumway-Cook A, Brown LA. Cognitive Influence on Postural Stability A Neuromuscular Analysis in Young and Older Adults. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences. 2000;55(3):M112–M119.

[67] Horak FB, Dimitrova D, Nutt JG. Direction-specific postural instability in subjects with Parkinson's disease. Experimental neurology. 2005;193(2):504–521.

[68] Rocchi L, Chiari L, Mancini M, Carlson-Kuhta P, Gross A, Horak FB. Step initiation in Parkinson's disease: influence of initial stance conditions. Neuroscience letters. 2006;406(1):128–132.

[69] Mancini M, Rocchi L, Horak FB, Chiari L. Effects of Parkinson's disease and levodopa on functional limits of stability. Clinical Biomechanics. 2008;23(4):450–458.

[70] Sibley KM, Beauchamp MK, Van Ooteghem K, Straus SE, Jaglal SB. Using the systems framework for postural control to analyze the components of balance evaluated in standardized balance measures: a scoping review. Archives of physical medicine and rehabilitation. 2015;96(1):122–132.

[71] Loftus SL. Qi Gong to Improve Postural Stability (QTIPS) for Parkinson Fall Prevention: A Neuroplasticity Approach. Topics in Geriatric Rehabilitation. 2014;30(1):58–69.

[72] Stylianou AP, McVey MA, Lyons KE, Pahwa R, Luchies CW. Postural sway in patients with mild to moderate Parkinson's disease. International Journal of Neuroscience. 2011;121(11):614–621.

[73] Haran F, Keshner EA. Sensory reweighting as a method of balance training for labyrinthine loss. Journal of neurologic physical therapy: JNPT. 2008;32(4):186.

[74] Frenklach A, Louie S, Koop MM, Bronte-Stewart H. Excessive postural sway and the risk of falls at different stages of Parkinson's disease. Movement Disorders. 2009;24(3):377–385.

[75] Bronstein A, Hood J, Gresty M, PANAGI C. Visual control of balance in cerebellar and parkinsonian syndromes. Brain. 1990;113(3):767–779.

[76] Chong RK, Horak FB, Woollacott MH. Time-dependent influence of sensorimotor set on automatic responses in perturbed stance. Experimental brain research. 1999;124(4):513–519.

[77] Azulay JP, Mesure S, Amblard B, Pouget J. Increased visual dependence in Parkinson's disease. Perceptual and motor skills. 2002;95(3f):1106–1114.

[78] Carpenter MG, Bloem BR. Postural control in Parkinson patients: a proprioceptive problem? Experimental neurology. 2011;227(1):26–30.

[79] Konczak J, Corcos DM, Horak F, Poizner H, Shapiro M, Tuite P, et al. Proprioception and motor control in Parkinson's disease. Journal of motor behavior. 2009;41(6):543–552.

[80] Tagliabue M, Ferrigno G, Horak F. Effects of Parkinson's disease on proprioceptive control of posture and reaching while standing. Neuroscience. 2009;158(4):1206–1214.

[81] Patel N, Jankovic J, Hallett M. Sensory aspects of movement disorders. The Lancet Neurology. 2014;13(1):100–112.

[82] Redgrave P, Rodriguez M, Smith Y, Rodriguez-Oroz MC, Lehericy S, Bergman H, et al. Goal-directed and habitual control in the basal ganglia: implications for Parkinson's disease. Nature Reviews Neuroscience. 2010;11(11):760–772.

[83] Galvan A, Smith Y. The primate thalamostriatal systems: anatomical organization, functional roles and possible involvement in Parkinson's disease. Basal Ganglia. 2011;1(4):179–189.

[84] Wu T, Hallett M. The cerebellum in Parkinson's disease. Brain. 2013;136(3):696–709.

[85] Barbieri G, Gissot AS, Fouque F, Casillas JM, Pozzo T, Pérennou D. Does proprioception contribute to the sense of verticality? Experimental brain research. 2008;185(4):545–552.

[86] Vaugoyeau M, Viel S, Assaiante C, Amblard B, Azulay J. Impaired vertical postural control and proprioceptive integration deficits in Parkinson's disease. Neuroscience. 2007;146(2):852–863.

[87] Nieves AV, Miyasaki JM, Lang AE. Acute onset dystonic camptocormia caused by lenticular lesions. Movement disorders. 2001;16(1):177–180.

[88] Lackner JR, DiZio P. Vestibular, proprioceptive, and haptic contributions to spatial orientation. Annu Rev Psychol. 2005;56:115–147.

[89] Boecker H, Ceballos-Baumann A, Bartenstein P, Weindl A, Siebner H, Fassbender T, et al. Sensory processing in Parkinson's and Huntington's disease. Brain. 1999;122(9):1651–1665.

[90] Berardelli A, Sabra A, Hallett M. Physiological mechanisms of rigidity in Parkinson's disease. Journal of Neurology, Neurosurgery & Psychiatry. 1983;46(1):45–53.

[91] Jacobs J, Horak F. Abnormal proprioceptive-motor integration contributes to hypometric postural responses of subjects with Parkinson's disease. Neuroscience. 2006;141(2):999–1009.

[92] Rabin E, Chen J, Muratori L, DiFrancisco-Donoghue J, Werner WG. Haptic feedback from manual contact improves balance control in people with Parkinson's disease. Gait & posture. 2013;38(3):373–379.

[93] Jeka JJ. Light touch contact as a balance aid. Physical Therapy. 1997;77(5):476–487.

[94] Krishnamoorthy V, Slijper H, Latash ML. Effects of different types of light touch on postural sway. Experimental Brain Research. 2002;147(1):71–79.

[95] King LA, Horak FB. Delaying mobility disability in people with Parkinson disease using a sensorimotor agility exercise program. Physical Therapy. 2009;89(4):384–393.

[96] Jull G, Janda V. Muscles and motor control in low back pain: assessment and management. Physical therapy of the low back New York: Churchill Livingstone. 1987;p. 253–78.

[97] Page P. Sensorimotor training: A "global" approach for balance training. Journal of Bodywork and Movement Therapies. 2006;10(1):77–84.

[98] Shumway-Cook A, Woollacott MH. Motor control: theory and practical applications. Lippincott Williams & Wilkins; 1995.

[99] Horak FB, Macpherson JM. Postural orientation and equilibrium. Comprehensive Physiology. 1996;.

[100] Foreman KB, Addison O, Kim HS, Dibble LE. Testing balance and fall risk in persons with Parkinson disease, an argument for ecologically valid testing. Parkinsonism & related disorders. 2011;17(3):166–171.

[101] Prokop T, Schubert M, Berger W. Visual influence on human locomotion modulation to changes in optic flow. Experimental brain research. 1997;114(1):63–70.

[102] Frost R, Skidmore J, Santello M, Artemiadis P. Sensorimotor control of gait: a novel approach for the study of the interplay of visual and proprioceptive feedback. Frontiers in human neuroscience. 2015;9.

[103] Lord SR, Dayhew J. Visual risk factors for falls in older people. Journal of the American Geriatrics Society. 2001;49(5):508–515.

[104] Roll R, Kavounoudias A, Roll JP. Cutaneous afferents from human plantar sole contribute to body posture awareness. Neuroreport. 2002;13(15):1957–1961.

[105] Shin Ss, An Dh, Yoo Wg. Comparison of gait velocity and center of mass acceleration under conditions of disrupted somatosensory input from the feet during the navigation of obstacles in older adults with good and poor visual acuity. European Geriatric Medicine. 2014;.

[106] Barrett D, Cobb A, Bentley G. Joint proprioception in normal, osteoarthritic and replaced knees. Journal of Bone & Joint Surgery, British Volume. 1991;73(1):53–56.

[107] Morris ME. Movement disorders in people with Parkinson disease: a model for physical therapy. Physical therapy. 2000;80(6):578–597.

[108] Alexander GE, DeLong MR, Strick PL. Parallel organization of functionally segregated circuits linking basal ganglia and cortex. Annual review of neuroscience. 1986;9(1):357–381.

[109] Grasso R, Peppe A, Stratta F, Angelini D, Zago M, Stanzione P, et al. Basal ganglia and gait control: apomorphine administration and internal pallidum stimulation in Parkinson's disease. Experimental brain research. 1999;126(2):139–148.

[110] Lewis GN, Byblow WD, Walt SE. Stride length regulation in Parkinson's disease: the use of extrinsic, visual cues. Brain. 2000;123(10):2077–2090.

[111] Švehlík M, Zwick EB, Steinwender G, Linhart WE, Schwingenschuh P, Katschnig P, et al. Gait analysis in patients with Parkinson's disease off dopaminergic therapy. Archives of physical medicine and rehabilitation. 2009;90(11):1880–1886.

[112] Haas CT, Buhlmann A, Turbanski S, Schmidtbleicher D. Proprioceptive and sensorimotor performance in Parkinson's disease. Research in Sports Medicine. 2006;14(4):273–287.

[113] Ebersbach G, Edler D, Kaufhold O, Wissel J. Whole body vibration versus conventional physiotherapy to improve balance and gait in Parkinson's disease. Archives of physical medicine and rehabilitation. 2008;89(3):399–403.

[114] Hackney ME, Earhart GM. Tai Chi improves balance and mobility in people with Parkinson disease. Gait & posture. 2008;28(3):456–460.

[115] Gao Q, Leung A, Yang Y, Wei Q, Guan M, Jia C, et al. Effects of Tai Chi on balance and fall prevention in Parkinson's disease: a randomized controlled trial. Clinical rehabilitation. 2014;28(8):748–753.

[116] Sage MD, Almeida QJ. A positive influence of vision on motor symptoms during sensory attention focused exercise for Parkinson's disease. Movement disorders. 2010;25(1):64–69.

[117] Sage MD, Johnston RE, Almeida QJ. Comparison of exercise strategies for motor symptom improvement in Parkinson's disease. Neurodegenerative Disease Management. 2011;1(5):387–395.

[118] Lefaivre SC, Almeida QJ. Can sensory attention focused exercise facilitate the utilization of proprioception for improved balance control in PD? Gait & posture. 2015;41(2):630–633.

[119] Li F, Harmer P, Fisher KJ, Xu J, Fitzgerald K, Vongjaturapat N. Tai Chi-based exercise for older adults with Parkinson's disease: a pilot-program evaluation. Journal of Aging and Physical Activity. 2007;15(2):139.

[120] Esculier JF, Vaudrin J, Beriault P, Gagnon K, Tremblay LE. Home-based balance training programme using Wii Fit with balance board for Parkinson's disease: a pilot study. Journal of Rehabilitation Medicine. 2012;44(2):144–150.

[121] Conradsson D, Löfgren N, Ståhle A, Hagströmer M, Franzén E. A novel conceptual framework for balance training in Parkinson's disease-study protocol for a randomised controlled trial. BMC neurology. 2012;12(1):111.

[122] Wong-Yu IS, Mak MK. Multi-dimensional balance training programme improves balance and gait performance in people with Parkinson's disease: A pragmatic randomized controlled trial with 12-month follow-up. Parkinsonism & related disorders. 2015;.

[123] Arias P, Chouza M, Vivas J, Cudeiro J. Effect of whole body vibration in Parkinson's disease: a controlled study. Movement Disorders. 2009;24(6):891–898.

[124] Chouza M, Arias P, Viñas S, Cudeiro J. Acute effects of whole-body vibration at 3, 6, and 9 hz on balance and gait in patients with Parkinson's disease. Movement Disorders. 2011;26(5):920–921.

[125] Haas CT, Turbanski S, Kessler K, Schmidtbleicher D. The effects of random whole-body-vibration on motor symptoms in Parkinson's disease. NeuroRehabilitation-An Interdisciplinary Journal. 2006;21(1):29–36.

[126] Sitjà Rabert M, Rigau Comas D, Fort Vanmeerhaeghe A, Santoyo Medina C, Roqué i Figuls M, Romero-Rodríguez D, et al. Whole-body vibration training for patients with neurodegenerative disease. The Cochrane Library. 2012;.

[127] Ahlskog JE. Does vigorous exercise have a neuroprotective effect in Parkinson disease? Neurology. 2011;77(3):288–294.

[128] Sehm B, Taubert M, Conde V, Weise D, Classen J, Dukart J, et al. Structural brain plasticity in Parkinson's disease induced by balance training. Neurobiology of aging. 2014;35(1):232–239.

[129] Goetz CG, Tilley BC, Shaftman SR, Stebbins GT, Fahn S, Martinez-Martin P, et al. Movement Disorder Society-sponsored revision of the Unified Parkinson's Disease Rating Scale (MDS-UPDRS): Scale presentation and clinimetric testing results. Movement disorders. 2008;23(15):2129–2170.

[130] Stebbins GT, Goetz CG. Factor structure of the Unified Parkinson's Disease Rating Scale: motor examination section. Movement Disorders. 1998;13(4):633–636.

[131] Jöbges M, Heuschkel G, Pretzel C, Illhardt C, Renner C, Hummelsheim H. Repetitive training of compensatory steps: a therapeutic approach for postural instability in Parkinson's disease. Journal of Neurology, Neurosurgery & Psychiatry. 2004;75(12):1682–1687.

[132] Goodwin VA, Richards SH, Taylor RS, Taylor AH, Campbell JL. The effectiveness of exercise interventions for people with Parkinson's disease: A systematic review and meta-analysis. Movement disorders. 2008;23(5):631–640.

[133] Almeida Q, Frank J, Roy E, Jenkins M, Spaulding S, Patla A, et al. An evaluation of sensorimotor integration during locomotion toward a target in Parkinson's disease. Neuroscience. 2005;134(1):283–293.

[134] Kim SD, Allen NE, Canning CG, Fung VS. Postural instability in patients with Parkinson's disease. CNS drugs. 2013;27(2):97–112.

[135] Chaikeeree N, Saengsirisuwan V, Chinsongkram B, Boonsinsukh R. Interaction of age and foam types used in Clinical Test for Sensory Interaction and Balance (CTSIB). Gait & posture. 2015;41(1):313–315.

[136] Fuentes CT, Bastian AJ. Where is your arm? Variations in proprioception across space and tasks. Journal of Neurophysiology. 2010;103(1):164–171.

[137] Vaugoyeau M, Hakam H, Azulay JP. Proprioceptive impairment and postural orientation control in Parkinson's disease. Human movement science. 2011;30(2):405–414.

[138] Bekkers EM, Dockx K, Heremans E, Vercruysse S, Verschueren SM, Mirelman A, et al. The contribution of proprioceptive information to postural control in elderly and patients with Parkinson's disease with a history of falls. Frontiers in human neuroscience. 2014;8.

[139] Wright WG, Gurfinkel V, King L, Horak F. Parkinson's disease shows perceptuomotor asymmetry unrelated to motor symptoms. Neuroscience letters. 2007;417(1):10–15.

[140] Paquette C, Franzén E, Jones GM, Horak FB. Walking in circles: navigation deficits from Parkinson's disease but not from cerebellar ataxia. Neuroscience. 2011;190:177–183.

[141] Vaugoyeau M, Azulay JP. Role of sensory information in the control of postural orientation in Parkinson's disease. Journal of the neurological sciences. 2010;289(1):66–68.

[142] Elangovan N, Herrmann A, Konczak J. Assessing proprioceptive function: evaluating joint position matching methods against psychophysical thresholds. Physical therapy. 2014;94(4):553–561.

[143] Hoops S, Nazem S, Siderowf A, Duda J, Xie S, Stern M, et al. Validity of the MoCA and MMSE in the detection of MCI and dementia in Parkinson disease. Neurology. 2009;73(21):1738–1745.

[144] Waddington GS, Adams RD. The Effect of a 5-Week Wobble-Board Exercise Intervention on Ability to Discriminate Different Degrees of Ankle Inversion, Barefoot and Wearing Shoes: A Study in Healthy Elderly. Journal of the American Geriatrics Society. 2004;52(4):573–576.

[145] Jenkinson C, Fitzpatrick R, Peto V, Greenhall R, Hyman N. The Parkinson's Disease Questionnaire (PDQ-39): development and validation of a Parkinson's disease summary index score. Age and ageing. 1997;26(5):353–357.

[146] Fitzgerald D, Trakarnratanakul N, Smyth B, Caulfield B. Effects of a wobble board-based therapeutic exergaming system for balance training on dynamic postural stability and intrinsic motivation levels. journal of orthopaedic & sports physical therapy. 2010;40(1):11–19.

[147] Thalheimer W, Cook S. How to calculate effect sizes from published research: A simplified methodology. Work-Learning Research. 2002;p. 1–9.

[148] Toole T, Hirsch M, Forkink A, Lehman D, Maitland C. The effects of a balance and strength training program on equilibrium in Parkinsonism: A preliminary study. NeuroRehabilitation. 1999;14(3):165–174.

[149] Yardley L, Beyer N, Hauer K, Kempen G, Piot-Ziegler C, Todd C. Development and initial validation of the Falls Efficacy Scale-International (FES-I). Age and ageing. 2005;34(6):614–619.

[150] Adkin AL, Frank JS, Jog MS. Fear of falling and postural control in Parkinson's disease. Movement Disorders. 2003;18(5):496–502.

[151] Rupp K, Muche PR, Nikolaus MT, Becker MC, et al. Improving balance by improving motor skills. Zeitschrift für Gerontologie und Geriatrie. 2004;37(1):20–26.

[152] Woollacott MH. Editorial Systems Contributing to Balance Disorders in Older Adults. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences. 2000;55(8):M424–M428.

[153] Yang YR, Lee YY, Cheng SJ, Lin PY, Wang RY. Relationships between gait and dynamic balance in early Parkinson's disease. Gait & posture. 2008;27(4):611–615.

[154] Nallegowda M, Singh U, Handa G, Khanna M, Wadhwa S, Yadav SL, et al. Role of sensory input and muscle strength in maintenance of balance, gait, and posture in Parkinson's disease: a pilot study. American journal of physical medicine & rehabilitation. 2004;83(12):898–908.

[155] Schneider JS, Diamond SG, Markham CH. Deficits in orofacial sensorimotor function in Parkinson's disease. Annals of neurology. 1986;19(3):275–282.

[156] Nilsson MH, Hariz GM, Iwarsson S, Hagell P. Walking ability is a major contributor to fear of falling in people with Parkinson's disease: implications for rehabilitation. Parkinson's disease. 2011;2012.

[157] Morris S, Morris ME, Iansek R. Reliability of measurements obtained with the Timed "Up & Go" test in people with Parkinson disease. Physical therapy. 2001;81(2):810–818.

[158] Park JH, Cho H, Shin JH, Kim T, Park SB, Choi BY, et al. Relationship among fear of falling, physical performance, and physical characteristics of the rural elderly. American Journal of Physical Medicine & Rehabilitation. 2014;93(5):379–386.

[159] Franchignoni F, Martignoni E, Ferriero G, Pasetti C. Balance and fear of falling in Parkinson's disease. Parkinsonism & related disorders. 2005;11(7):427–433.

[160] Baldan A, Alouche S, Araújo I, Freitas S. Effect of light touch on postural sway in individuals with balance problems: A systematic review. Gait & posture. 2014;40(1):1–10.

[161] Gopalai AA, Senanayake S, Arosha M. A wearable real-time intelligent posture corrective system using vibrotactile feedback. Mechatronics, IEEE/ASME Transactions on. 2011;16(5):827–834.

[162] Rabin E, Muratori L, Svokos K, Gordon A. Tactile/proprioceptive integration during arm localization is intact in individuals with Parkinson's disease. Neuroscience letters. 2010;470(1):38–42.

[163] Rabin E, DiZio P, Ventura J, Lackner JR. Influences of arm proprioception and degrees of freedom on postural control with light touch feedback. Journal of neurophysiology. 2008;99(2):595–604.

[164] Martin JP. The basal ganglia and posture. Lippincott; 1967.

[165] Luessi F, Mueller L, Breimhorst M, Vogt T. Influence of visual cues on gait in Parkinson's disease during treadmill walking at multiple velocities. Journal of the neurological sciences. 2012;314(1):78–82.

[166] Rocchi L, Chiari L, Horak F. Effects of deep brain stimulation and levodopa on postural sway in Parkinson's disease. Journal of Neurology, Neurosurgery & Psychiatry. 2002;73(3):267–274.

[167] Horak F, Frank J, Nutt J. Effects of dopamine on postural control in parkinsonian subjects: scaling, set, and tone. Journal of Neurophysiology. 1996;75(6):2380–2396.

[168] Bejjani BP, Gervais D, Arnulf I, Papadopoulos S, Demeret S, Bonnet AM, et al. Axial parkinsonian symptoms can be improved: the role of levodopa and bilateral subthalamic stimulation. Journal of Neurology, Neurosurgery & Psychiatry. 2000;68(5):595–600.

[169] Diem-Zangerl A, Seppi K, Wenning GK, Trinka E, Ransmayr G, Oberaigner W, et al. Mortality in Parkinson's disease: A 20-year follow-up study. Movement disorders. 2009;24(6):819–825.

[170] Mehanna R, Moore S, Hou JG, Sarwar AI, Lai EC. Comparing clinical features of young onset, middle onset and late onset Parkinson's disease. Parkinsonism & related disorders. 2014;20(5):530–534.

[171] Rochester L, Hetherington V, Jones D, Nieuwboer A, Willems AM, Kwakkel G, et al. Attending to the task: interference effects of functional tasks on walking in Parkinson's disease and the roles of cognition, depression, fatigue, and balance. Archives of physical medicine and rehabilitation. 2004;85(10):1578–1585.

[172] Lin CC, Roche JL, Steed DP, Musolino MC, Marchetti GF, Furman GR, et al. Test-retest reliability of postural stability on two different foam pads. Journal of nature and science. 2015;1(2):e43.

[173] Allum J, Zamani F, Adkin A, Ernst A. Differences between trunk sway characteristics on a foam support surface and on the Equitest® ankle-sway-referenced support surface. Gait & posture. 2002;16(3):264–270.

[174] King LA, Horak FB, Mancini M, Pierce D, Priest KC, Chesnutt J, et al. Instrumenting the balance error scoring system for use with patients reporting persistent balance problems after mild traumatic brain injury. Archives of physical medicine and rehabilitation. 2014;95(2):353–359.

[175] Jeka JJ, Lackner JR. Fingertip contact influences human postural control. Experimental Brain Research. 1994;79(2):495–502.

[176] Reginella RL, Redfern MS, Furman JM. Postural sway with earth-fixed and body-referenced finger contact in young and older adults. Journal of vestibular research: equilibrium & orientation. 1998;9(2):103–109.

[177] Powell LE, Myers AM. The activities-specific balance confidence (ABC) scale. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences. 1995;50(1):M28–M34.

[178] Dal Bello-Haas V, Klassen L, Sheppard MS, Metcalfe A. Psychometric properties of activity, self-efficacy, and quality-of-life measures in individuals with Parkinson disease. Physiotherapy Canada. 2015;.

[179] Rodriguez-Blazquez C, Rojo-Abuin JM, Alvarez-Sanchez M, Arakaki T, Bergareche-Yarza A, Chade A, et al. The MDS-UPDRS Part II (motor experiences of daily living) resulted useful for assessment of disability in Parkinson's disease. Parkinsonism & related disorders. 2013;19(10):889–893.

[180] Franzén E, Paquette C, Gurfinkel V, Horak F. Light and heavy touch reduces postural sway and modifies axial tone in Parkinson's disease. Neurorehabilitation and neural repair. 2012;26(8):1007–1014.

[181] Mak MK, Pang MY. Balance confidence and functional mobility are independently associated with falls in people with Parkinson's disease. Journal of neurology. 2009;256(5):742–749.

[182] Holden M, Ventura J, Lackner JR. Stabilization of posture by precision contact of the index finger. J Vestib Res. 1994;4(4):285–301.

[183] Tremblay F, Mireault AC, Dessureault L, Manning H, Sveistrup H. Postural stabilization from fingertip contact: I. Variations in sway attenuation, perceived stability and contact forces with aging. Experimental brain research. 2004;157(3):275–285.

[184] Baldereschi M, Di Carlo A, Rocca W, Vanni P, Maggi S, Perissinotto E, et al. Parkinson's disease and parkinsonism in a longitudinal study Two-fold higher incidence in men. Neurology. 2000;55(9):1358–1363.

[185] Taylor K, Cook J, Counsell C. Heterogeneity in male to female risk for Parkinson's disease. Journal of Neurology, Neurosurgery & Psychiatry. 2007;78(8):905–906.

[186] Gillies GE, Pienaar IS, Vohra S, Qamhawi Z. Sex differences in Parkinson's disease. Frontiers in neuroendocrinology. 2014;35(3):370–384.

[187] Elbaz A, Bower JH, Maraganore DM, McDonnell SK, Peterson BJ, Ahlskog JE, et al. Risk tables for parkinsonism and Parkinson's disease. Journal of clinical epidemiology. 2002;55(1):25–31.

[188] Bourque M, Dluzen DE, Di Paolo T. Neuroprotective actions of sex steroids in Parkinson's disease. Frontiers in neuroendocrinology. 2009;30(2):142–157.

[189] Semchuk KM, Love EJ, Lee RG. Parkinson's disease and exposure to agricultural work and pesticide chemicals. Neurology. 1992;42(7):1328–1328.

[190] Lehman EJ, Hein MJ, Baron SL, Gersic CM. Neurodegenerative causes of death among retired National Football League players. Neurology. 2012;79(19):1970–1974.

[191] Pescatello LS. ACSM's guidelines for exercise testing and prescription. Lippincott Williams & Wilkins; 2013.

[192] Hue O, Simoneau M, Marcotte J, Berrigan F, Doré J, Marceau P, et al. Body weight is a strong predictor of postural stability. Gait & posture. 2007;26(1):32–38.

[193] Greve J, Alonso A, Bordini ACP, Camanho GL. Correlation between body mass index and postural balance. Clinics. 2007;62(6):717–720.

[194] Corbeil P, Simoneau M, Rancourt D, Tremblay A, Teasdale N. Increased risk for falling associated with obesity: mathematical modeling of postural control. Neural Systems and Rehabilitation Engineering, IEEE Transactions on. 2001;9(2):126–136.

[195] Goetz CG, Poewe W, Rascol O, Sampaio C, Stebbins GT, Counsell C, et al. Movement Disorder Society Task Force report on the Hoehn and Yahr staging scale: status and recommendations the Movement Disorder Society Task Force on rating scales for Parkinson's disease. Movement disorders. 2004;19(9):1020–1028.

[196] Camicioli R, Majumdar SR. Relationship between mild cognitive impairment and falls in older people with and without Parkinson's disease: 1-Year Prospective Cohort Study. Gait & posture. 2010;32(1):87–91.

[197] Brusse KJ, Zimdars S, Zalewski KR, Steffen TM. Testing functional performance in people with Parkinson disease. Physical therapy. 2005;85(2):134–141.

[198] Zampieri C, Salarian A, Carlson-Kuhta P, Aminian K, Nutt JG, Horak FB. An instrumented timed up and go test characterizes gait and postural transitions in untreated parkinson's disease. Journal of Neurology, Neurosurgery & Psychiatry. 2009;.

[199] Tinetti ME, Inouye SK, Gill TM, Doucette JT. Shared risk factors for falls, incontinence, and functional dependence: unifying the approach to geriatric syndromes. Jama. 1995;273(17):1348–1353.

[200] Massion J. Postural control system. Current opinion in neurobiology. 1994;4(6):877–887.

[201] Mergner T, Rosemeier T. Interaction of vestibular, somatosensory and visual signals for postural control and motion perception under terrestrial and microgravity conditionsÑa conceptual model. Brain Research Reviews. 1998;28(1):118–135.

[202] Riemann BL, Lephart SM. The sensorimotor system, part II: the role of proprioception in motor control and functional joint stability. Journal of athletic training. 2002;37(1):80.

[203] Dibble LE, Lange M. Predicting falls in individuals with Parkinson disease: a reconsideration of clinical balance measures. Journal of Neurologic Physical Therapy. 2006;30(2):60–67.

[204] Herman T, Giladi N, Hausdorff JM. Properties of the 'timed up and go'test: more than meets the eye. Gerontology. 2011;57(3):203–210.

[205] Mun-San Kwan M, Lin SI, Chen CH, Close JC, Lord SR. Sensorimotor function, balance abilities and pain influence Timed Up and Go performance in older community-living people. Aging clinical and experimental research. 2011;23(3):196–201.

[206] Huang SL, Hsieh CL, Wu RM, Tai CH, Lin CH, Lu WS. Minimal detectable change of the Timed "Up & Go" Test and the Dynamic Gait Index in people with Parkinson disease. Physical Therapy. 2011;91(1):114–121.

[207] King LA, Mancini M, Priest K, Salarian A, Rodrigues-de Paula F, Horak F. Do clinical scales of balance reflect turning abnormalities in people with Parkinson's disease? Journal of Neurologic Physical Therapy. 2012;36(1):25.

[208] Schenkman M, Ellis T, Christiansen C, Barón AE, Tickle-Degnen L, Hall DA, et al. Profile of functional limitations and task performance among people with early-and middle-stage Parkinson disease. Physical therapy. 2011;91(9):1339–1354.

[209] Martínez-Martín P, Deuschl G. Effect of medical and surgical interventions on health-related quality of life in Parkinson's disease. Movement disorders. 2007;22(6):757–765.

[210] Almeida LR, Valença GT, Negreiros NN, Pinto EB, Oliveira-Filho J. Recurrent Falls in People with Parkinson's Disease without Cognitive Impairment: Focusing on Modifiable Risk Factors. Parkinson's Disease. 2014;2014.

Appendices

Appendix A

Aims and Objectives for Somatosensory Training Program

Week 1

Aim: Familiarization and alignment

1. To increase proprioceptive input to foot, sacro-iliac joint (SIJ) and cervical spine to ensure proper positioning during exercise sessions.

Session 1	**Session 2**	**Session 3**
Objective: Foot proprioception	*Objective:* SIJ proprioception	*Objective:* Cervical spine proprioception
• Short foot	• Short foot • Neutral pelvic positions	• Short foot • Neutral pelvic positions • Neutral neck positions i.e. chin tucked in

Week 2

Aim: Static balance

1. To maintain postural control on unstable surfaces and progress to weight shifting, eliminating vision or adding head movements.
2. Focus on using the ankle strategy during exercise sessions.

Session 1	**Session 2**	**Session 3**
Objective: Posture	*Objective:* Base of support	*Objective:* Centre of gravity

Week 3

Aim: Static balance

1. To maintain postural control on unstable surfaces and progress to weight shifting, eliminating vision or adding head movements.
2. Focus on using the ankle strategy during exercise sessions and introduce hip strategy.

Session 1	**Session 2**	**Session 3**
Objective: Posture	*Objective:* Base of support	*Objective:* Centre of gravity

Week 4

Aim: Dynamic balance

1. To maintain postural control on progressively unstable surfaces while adding upper- and lower extremity movement.
2. Maintain ankle strategy during exercise sessions and focus hip strategy.

Session 1	**Session 2**	**Session 3**
Objective: Posture	*Objective:* Base of support	*Objective:* Centre of gravity

Week 5

Aim: Dynamic balance

1. To maintain postural control on progressively unstable surfaces while adding upper- and lower extremity movement.
2. Maintain ankle strategy, focus on hip strategy and start introducing stepping strategy in exercise sessions

Session 1	**Session 2**	**Session 3**
Objective: Posture	*Objective:* Base of support	*Objective:* Centre of gravity

Week 6

Aim: Functional balance

1. To perform functional movements of everyday life on progressively unstable surfaces.
2. Maintain ankle and hip strategy and focus on stepping strategy in exercise sessions

Session 1	**Session 2**	**Session 3**
Objective: Posture	*Objective:* Base of support	*Objective:* Centre of gravity

Week 7

Aim: Functional balance

1. To perform functional movements of everyday life on progressively unstable surfaces.
2. Maintain ankle and hip strategy and focus on stepping strategy in exercise sessions

Session 1	**Session 2**	**Session 3**
Objective: Posture	*Objective:* Base of support	*Objective:* Centre of gravity

Week 8

Aim: Functional balance

1. To perform functional movements of everyday life on progressively unstable surfaces.
2. Maintain ankle and hip strategy and focus on stepping strategy in exercise sessions

Session 1	**Session 2**	**Session 3**
Objective: Posture	*Objective:* Base of support	*Objective:* Centre of gravity

Appendix B

Somatosensory Training Program Design

Safety guidelines for participants:

The following safety guidelines are tips to keep in mind while doing somatosensory training. Please make yourself familiar with its contents before you start the eight-week intervention program.

- Nothing should hurt. This is a simple rule, if it hurts inform the instructor. You should never get the idea that you should grin and just bear it. Nothing should hurt, cause physical problems or should make you feel uncomfortable or anxious.
- Arm's-length rule. Whenever you are not sitting, you should be no farther than an arm's length away from a balance support. This support will usually be a sturdy chair, but it could also be a walker or cane, handrail or counter, partner or assistant or even the instructor's hand.
- Ninety percent rule. This rule says that you should attempt only what you are ninety percent confident you can do safely - that is, what you are pretty sure you can do.
- Choose or refuse rule. Participation is always your own choice. If any activity makes you uncomfortable, stop and wait until you have the confidence to proceed.
- Signs to stop an activity immediately. Please inform the instructor if you experience any of the symptoms below:
  - Dizziness and/or nausea
  - Shortness of breath
  - Unusual fatigue

  - Heart racing or pounding
  - Uneasiness or anxiety
  - Blurred vision or slurred speech
  - Pain or tightness in chest, jaw or arm
  - Sudden paleness or clammy skin

- Medication, medication, medication. Please ensure that you take your medication as per your prescription. The exercise sessions should not serve as a substitution for your medication.
- Make sure you understand. Please inform the instructor if any of the exercises or movements are not completely understood. This will increase your chance of benefiting from the program.
- Good posture. The following points on posture should be maintained throughout the session:
  - Stand/sit up straight
  - Keep shoulders back
  - Keep abdomen tucked in
  - Keep feet flat on the floor
- In case of EMERGENCY. The following steps should be followed in case any participant becomes severely ill, disorientated, falls and/or gets injured:
  - Stop exercising immediately
  - Inform the instructor if necessary
  - Any participants standing should sit down
  - Clear the area around the injured participant
  - Make the participant as comfortable as possible

Warm-up and Cool-down before each session

Warm-up (10min)	Cool-down (5min)
Circle soccer • Whole body stretches ▪ Shoulder circles ▪ Neck stretch ▪ Arm stretch ▪ Arm push ▪ Arm circles ▪ Back squeezes ▪ Hugs ▪ Wrist circles ▪ Thumb to finger ▪ Quadricep stretch ▪ Hamstrings stretch ▪ Calf stretch ▪ Deep breathing	• Deep breathing • Muscular relaxation (@chair) ▪ Hands ▪ Arms ▪ Neck ▪ Face ▪ Chest ▪ Stomach ▪ Buttocks ▪ Legs • Deep breathing ▪ Chin-to-chest ▪ Chin-to-shoulder ▪ Trunk rotation ▪ Close eyes

Week 1

Session 1 - Foot alignment	Session 2 – SIJ alignment	Session 3 – Cervical spine alignment
• Cue Posture • Short foot training ▪ Sitting: Passive modelling or hand positioning ▪ Standing: - try to maintain short foot (SF) - modified tandem stance with SF - one leg balance with SF - pick foot up in air and maintain SF • Curl toes up and increase arch (pull towards heel) • Toe abduction (spreading) • Towel dragging ▪ Inversion, Eversion ▪ Plantar flexion ▪ Marble pick ups	• Cue posture • Short foot training (recap) – 10min • SIJ training ▪ Seated: - Pelvic tilt ▪ Standing: - Pelvic tilt - try to maintain short foot (SF) - one leg balance with SF - modified tandem stance with SF • Weight shifts with TA activation	• Cue posture • Short foot training (recap) • Cervical spine training with SIJ training ▪ Repeat SIJ training with nodding movement of head ▪ (Roll shoulders, arms down, someone is pulling on your ears, chin in)

Week 2

Session 1 - Posture	Session 2 – Base of Support	Session 3 – Centre of Gravity
• Cue Posture • Balance exercises ▪ Sitting with feet on firm surface: - trunk leans in different directions - Reaching for objects - Catching and throwing objects (group) ▪ Standing with feet on firm surface: - Eyes open - Trunk leans in different directions - Reaching for objects - Catching and throwing objects (group) ▪ Modified Tandem stance: - Eyes open • Somatosensory activity ▪ The ball game ▪ Over the moon ▪ Over the moon – rock forward, step up	• Cue posture • Balance exercises ▪ Standing with feet on firm surface: - Eyes open - Trunk leans in different directions - Reaching for objects - Catching and throwing objects (group) ▪ Modified Tandem stance: - Eyes open - Trunk leans in different directions - Reaching for objects - Catching and throwing objects (group) ▪ Single leg stance: - Eyes open • Somatosensory activity ▪ Belly button training ▪ Standing weight shifts	• Cue posture • Balance exercises ▪ Standing with feet on firm surface: - Eyes open - Trunk leans in different directions - Reaching for objects - Catching and throwing objects (group) ▪ Modified Tandem stance: - Eyes open - Dim room lights - Dark glasses ▪ Single leg stance: - Eyes open - Dim room lights - Dark glasses • Somatosensory activity ▪ Standing weight shifts ▪ Making waves

Week 3

Session 1 - Posture	Session 2 – Base of Support	Session 3 – Centre of Gravity
• Cue Posture • Balance exercises ▪ Sitting with feet on firm surface: - trunk leans in different directions - Reaching for objects - Catching and throwing objects (group) ▪ Standing with feet on firm surface: - trunk leans in different directions - Reaching for objects - Catching and throwing objects (group) ▪ Modified Tandem stance on firm surface: - Eyes open - Dark glasses - One eye closed - Both eyes closed • Somatosensory activity ▪ Standing weight shifts ▪ Making waves	• Cue posture • Balance exercises ▪ Standing with feet on firm surface: - trunk leans in different directions - Reaching for objects - Catching and throwing objects (group) ▪ Modified Tandem stance on firm surface: - Eyes open - Dark glasses - One eye closed - Both eyes closed ▪ Single leg stance on firm surface: - Eyes open - Dark glasses - One eye closed - Both eyes closed • Somatosensory activity Keeping you on your toes	• Cue posture • Balance exercises ▪ Standing with feet on firm surface: - trunk leans in different directions - Reaching for objects - Catching and throwing objects (group) ▪ Modified Tandem stance on firm surface: - Eyes open - Dark glasses - One eye closed - Both eyes closed ▪ Single leg stance on firm surface: - Eyes open - Dark glasses - One eye closed - Both eyes closed • Somatosensory activity ▪ Rock and walk

Week 4

Session 1 - Posture	Session 2 – Base of Support	Session 3 – Centre of Gravity
• Cue Posture • Balance exercises ▪ Modified Tandem stance on firm surface: - Eyes open - Dark glasses - One eye closed - Both eyes closed ▪ Single leg stance on firm surface: - Eyes open - Dark glasses - One eye closed - Both eyes closed ▪ Walking (15m) - normal walking - high knees walking - butt kicks walking - sideways walking • Somatosensory activity ▪ Opposing circles and high fives	• Cue posture • Balance exercises ▪ Modified Tandem stance on firm surface: - Eyes open - Dark glasses - One and both eyes closed ▪ Single leg stance on firm surface: - Eyes open - Dark glasses - One eye closed - Both eyes closed ▪ Walking (15m) - normal walking - high knees walking - butt kicks walking ▪ Tandem Walking ▪ Weight shifts with stepping strategy • Somatosensory activity ▪ Follow the light	• Cue posture • Balance exercises ▪ Single leg stance on firm surface: - Eyes open - Dark glasses - One eye closed - Both eyes closed ▪ Walking (15m) - normal walking - high knees walking - butt kicks walking - sideways walking ▪ Tandem Walking ▪ Weight shifts with stepping strategy ▪ Walking with reduced vision (15m) - high knees walking - butt kicks walking - sideways walking • Somatosensory activity ▪ Agility ladders

Week 5

Session 1 - Posture	Session 2 – Base of Support	Session 3 – Centre of Gravity
• Cue Posture • Balance exercises ▪ Single leg stance on compliant surface: - Eyes open - Dark glasses - One eye closed - Both eyes closed ▪ Walking (15m) - normal walking - high knees walking - butt kicks walking - sideways walking ▪ Weight shifts with stepping strategy ▪ Walking with reduced vision (15m) - normal walking - high knees walking - butt kicks walking - sideways walking • Somatosensory activity ▪ Opposing circles and high fives	• Cue posture • Balance exercises ▪ Walking (15m) - normal walking - high knees walking - butt kicks walking - sideways walking ▪ Tandem Walking ▪ Weight shifts with stepping strategy ▪ Walking with reduced vision (15m) - normal walking - high knees walking - butt kicks walking - sideways walking ▪ Tandem Walking with reduced vision ▪ Weight shifts with stepping strategy with reduced vision • Somatosensory activity ▪ Follow the light	• Cue posture • Balance exercises ▪ Walking (15m) - normal walking - high knees walking - butt kicks walking - sideways walking ▪ Tandem Walking ▪ Weight shifts with stepping strategy ▪ Walking with reduced vision (15m) - normal walking - high knees walking - butt kicks walking - sideways walking ▪ Tandem Walking with reduced vision ▪ Weight shifts with stepping strategy with reduced vision • Somatosensory activity ▪ Agility ladders

Week 6

Session 1 - Posture	Session 2 – Base of Support	Session 3 – Centre of Gravity
• Cue posture • Balance exercises ▪ Recap Modified Tandem stance on firm ▪ Recap Single leg stance on firm surface: ▪ Recap Walking (15m) ▪ Tandem Walking ▪ Weight shifts with stepping strategy ▪ Recap Walking with reduced vision (15m) ▪ Tandem Walking with reduced vision ▪ Weight shifts with stepping strategy with reduced vision ▪ Walking with reduced vision & head movements (15m) - normal walking - high knees walking - butt kicks walking - sideways walking • Somatosensory activity ▪ Agility ladders	• Cue posture • Balance exercises ▪ Recap Walking (15m) ▪ Tandem Walking ▪ Weight shifts with stepping strategy ▪ Recap Walking with reduced vision (15m) ▪ Tandem Walking with reduced vision ▪ Weight shifts with stepping strategy with reduced vision ▪ Walking with reduced vision & head movements (15m) - normal walking - high knees walking - butt kicks walking - sideways walking • Somatosensory activity ▪ Agility ladders	• Cue posture • Balance exercises ▪ Recap Walking (15m) ▪ Tandem Walking ▪ Weight shifts with stepping strategy ▪ Recap Walking with reduced vision (15m) ▪ Tandem Walking with reduced vision ▪ Weight shifts with stepping strategy with reduced vision ▪ Walking with reduced vision & head movements (15m) - normal walking - high knees walking - butt kicks walking - sideways walking • Somatosensory activity ▪ Agility ladders

Week 7

Session 1 - Posture	Session 2 – Base of Support	Session 3 – Centre of Gravity
• Cue posture • Balance exercises ▪ Recap Modified Tandem stance on firm ▪ Recap Single leg stance on firm surface: ▪ Walking (15m) with added obstacles ▪ Tandem Walking ▪ Reaching exercises - Reaching high on shelf - Reaching shoulder height - Reaching down to ground ▪ Weight shifts with stepping strategy ▪ Walking with direction change *(t-test)* ▪ Tandem Walking with reduced vision ▪ Weight shifts with stepping strategy with reduced vision ▪ Walking and counting (15m) ▪ Group Sit-to-stands in circle (move from chair 1 to chair 2)	• Cue posture • Balance exercises ▪ Recap Modified Tandem stance on firm ▪ Recap Single leg stance on firm surface: ▪ Walking (15m) with added obstacles ▪ Tandem Walking ▪ Reaching exercises - Reaching high on shelf - Reaching shoulder height - Reaching down to ground ▪ Weight shifts with stepping strategy ▪ Walking with direction change *(t-test)* ▪ Tandem Walking with reduced vision ▪ Weight shifts with stepping strategy with reduced vision ▪ Walking and counting (15m) ▪ Group Sit-to-stands in circle (move from chair 1 to chair 2)	• Cue posture • Balance exercises ▪ Recap Modified Tandem stance on firm ▪ Recap Single leg stance on firm surface: ▪ Walking (15m) with added obstacles ▪ Tandem Walking ▪ Reaching exercises - Reaching high on shelf - Reaching shoulder height - Reaching down to ground ▪ Weight shifts with stepping strategy ▪ Walking with direction change (t-test) ▪ Tandem Walking with reduced vision ▪ Weight shifts with stepping strategy with reduced vision ▪ Walking and counting (15m) ▪ Group Sit-to-stands in circle ▪ (move from chair 1 to chair 2)

Week 8

Session 1 - Posture	Session 2 – Base of Support	Session 3 – Centre of Gravity
• Cue posture • Balance exercises ▪ Recap Modified Tandem stance on firm ▪ Recap Single leg stance on firm surface: ▪ Walking with added obstacles and music ▪ Tandem Walking ▪ Reaching exercises with reduced vision - Reaching high on shelf - Reaching shoulder height - Reaching down to ground ▪ Weight shifts with stepping strategy ▪ Walking with direction change and obstacles (t-test) ▪ Tandem Walking with reduced vision ▪ Walking and counting backwards (15m) ▪ Group Sit-to-stands in circle (move from chair 1 to chair 2) ▪ 360° turns	• Cue posture • Balance exercises ▪ Walking with added obstacles and music ▪ Tandem Walking ▪ Weight shifts with stepping strategy ▪ Walking with direction change and obstacles (t-test) ▪ Tandem Walking with reduced vision ▪ Walking and counting backwards (15m) ▪ Group Sit-to-stands in circle (move from chair 1 to chair 2) ▪ 360° turns ▪ Sitting on Swiss Ball ▪ Sitting on Swiss Ball + Reaching exercises - Reaching high on shelf - Reaching shoulder height - Reaching down to ground	• Cue posture • Balance exercises ▪ Walking with added obstacles and music ▪ Tandem Walking ▪ Weight shifts with stepping strategy ▪ Walking with direction change and obstacles (t-test) ▪ Tandem Walking with reduced vision ▪ Walking and counting backwards (15m) ▪ Group Sit-to-stands in circle ▪ (move from chair 1 to chair 2) ▪ 360° turns ▪ Sitting on Swiss Ball ▪ Sitting on Swiss Ball + Reaching exercises - Reaching high on shelf - Reaching shoulder height - Reaching down to ground

Appendix C

Parkinson's Disease Quality of Life Questionnaire (PDQ-39)

Parkinson's Disease Quality of Life Questionnaire (PDQ-39)

Due to having Parkinson's disease,
how often during the last month have you…

Please tick one box for each question

		Never	Occasionally	Sometimes	Often	Always or cannot do at all
1.	Had difficulty doing the leisure activities which you would like to do?	☐	☐	☐	☐	☐
2.	Had difficulty looking after your home, e.g. DIY, housework, cooking?	☐	☐	☐	☐	☐
3.	Had difficulty carrying bags of shopping?	☐	☐	☐	☐	☐
4.	Had problems walking half a mile?	☐	☐	☐	☐	☐
5.	Had problems walking 100 yards?	☐	☐	☐	☐	☐
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?	☐	☐	☐	☐	☐

Please check that you have ticked one box for each question before going onto the next page.

Due to having Parkinso**n's disease,**
how often during the last month have you…

Please tick one box for each question

		Never	Occasionally	Sometimes	Often	Always or cannot do at all
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?	☐	☐	☐	☐	☐
13.	Had problems doing up buttons or shoe laces?	☐	☐	☐	☐	☐
14.	Had problems 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?	☐	☐	☐	☐	☐

Please check that you have ticked one box for each question
before going onto the next page.

Due to having Parkinson's disease,
how often during the last month have you…

Please tick one box for each question

		Never	Occasionally	Sometimes	Often	Always
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?	☐	☐	☐	☐	☐

Please check that you have ticked one box for each question
before going onto the next page.

Due to having Parkinson's disease,
how often during the last month have you…

Please tick one box for each question

		Never	Occasionally	Sometimes	Often	Always
28.	Lacked support in the ways you need from your spouse or partner? If you do not have a spouse or partner, please 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?	☐	☐	☐	☐	☐

Please check that you have ticked one box for each question
before going onto the next page.

Due to ha**ving Parkinson's disease,**
how often during the last month have you…

Please tick one box for each question

		Never	Occasionally	Sometimes	Often	Always
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 questionnaire.

Appendix D

Fall Efficacy Scale-International (FES-I)

Fall Efficacy Scale – International (FES-I)

For each of the following activities, please tick the opinion closest to your own to show how concerned you are that you might fall if you did this activity. Please reply thinking about how you usually do the activity. If you currently don't do the please answer to show whether you think you would be concerned about falling IF you did the activity.

Name: _____ **Surname:** _____ **Date:** _____	Not at all concerned 1	Somewhat concerned 2	Fairly concerned 3	Very concerned 4
Cleaning the house (e.g. sweep, dust)				
Getting dressed or undressed				
Preparing simple meals				
Taking a bath or shower				
Going to the shop				
Getting in or out of a chair				
Going up or down stairs				
Walking around in the neighbourhood				
Reaching for something above your head or on the ground				
Going to answer the telephone before it stops ringing				
Walking on a slippery surface (e.g. wet or icy)				
Visiting a friend or relative				
Walking in a place with crowds				
Walking on an uneven surface (e.g. rocky ground				
Walking up or down a slope				
Going out to a social event (e.g. family gathering, or club meeting)				
Total: /64				

Appendix E

The Activities-specific Balance Confidence Scale (ABC)

The Activities-Specific Balance Confidence Scale (ABC)

Date: _____ Print name: _____

Signature: _____

For each of the following, please indicate your level of confidence in doing the following activities without losing your balance or becoming unsteady by choosing one of the percentage points on the scale from 0% to 100%. If you do not currently do the activity in question, try and imagine how confident you would be if you had to do the activity. If you normally use walking aid to do the activity or hold onto someone, rate your confidence as if you were using these supports. If you have any questions about answering any of the following, please ask the administrator.

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 something off the floor?

____ % 4. Reach for a small can off a shelf at eye level?

____ % 5. Stand on your tiptoes and reach for something above your head?

____ % 6. Sweep the floor?

____ % 7. Walk outside the house to a parked car in the driveway?

____ % 8. Stand on a chair and reach for something?

____ % 9. Get in or out of a car?

____ % 10. Walk across a large parking lot?

____ % 11. Walk up or down a ramp?

____ % 12. Walk in a crowded place where people rapidly walk past you?

____ % 13. When you are bumped into by people when you are walking?

____ % 14. Step on or off an escalator while holding the rail?

____ % 15. Step on or off an escalator while holding items so that you cannot hold the railing?

____ % 16. Walk outside on icy or slippery sidewalks?

_____ : **TOTAL SCORE**

Appendix F

Informed Consent

UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
jou kennisvennoot • your knowledge partner

STELLENBOSCH UNIVERSITY

CONSENT TO PARTICIPATE IN RESEARCH

Somatosensory training for postural control in independent-living individuals with Parkinson's disease.

You are asked to participate in a research study conducted by Tania Gregory (Main researcher, Biokineticist & MSc Student) and Dr Karen Welman (Study Leader & Biokineticist) from the Sport Science Department at Stellenbosch University. The results will contribute to a research paper and MSc Thesis as well as to the pool of knowledge on Parkinson's disease. You were selected as a possible participant in this study since you meet the inclusion criteria, of the study.

1. PURPOSE OF THE STUDY

Main aim:

To establish if eight weeks of a particular somatosensory intervention will influence balance in individuals with mild to moderate Parkinson's disease (PD).

Terminology:

Somatosensory – the sensory systems responsible for the touch sensation as well as body and special awareness.

Postural control - also known as balance, specifically static (stationary) and dynamic (while moving).

2. PROCEDURES

Data collection will take 4 sessions to be completed over a 16-week period. The first interaction with the researchers will be done through a telephonic interview (session 1) where the researcher(s) will introduce themselves and discuss this informed consent form with you. During this session you will be asked to verbally give consent to participate in the study as well as sign this consent during the next visit. Please note you can ask questions and withdraw at any time during the study. Only after you have given consent and if you qualify for the inclusion criteria will you be included in the study.

You will be visited, or asked to visit the motor learning laboratory, six times after the telephonic interview; unless unforeseen problems occur then an additional visit will be scheduled (at a convenient time for all parties involved). Each data collection visit will last between 60 and 90 minutes.

For the purpose of this study, you will be asked to complete eight weeks of baseline testing, since every person is their own control. During these eight weeks you will continue your normal daily activities. Hereafter you will be randomly divided into one of the following somatosensory interventions, specifically either the feedback-wristband or somatosensory-training group program. All participants will receive a balance-training DVD after completion of the study.

We will ask you to complete questionnaires relative to your condition, health, mood, activity status, balance, and concern of falling. These questionnaires will be sent to you and must be completed for the next visit. During the following visits, testing will take place while you are on medication. We will measure your weight and height as well as perform a few tests to assess your balance. None of these tests are invasive. Sessions 2 will be scheduled before your eight weeks of baseline (normal daily activities) start. Sessions 3 will be scheduled after the eight weeks of baseline and sessions 4 after the eight weeks of the intervention. Session 4 will be a repeat of sessions 2 and 3.

3. INTERVENTION

You will be randomly divided into either a somatosensory-training group or a feedback wristband group. These are both somatosensory interventions and will continue for eight-weeks after the baseline period. Both of the groups will receive a balance training DVD after completing the study interventions and all the assessments.

Somatosensory-training group sessions

For the somatosensory group sessions, you will be required to complete 3 sessions per week at the Motor Learning Laboratory in Stellenbosch. These sessions will only focus on balance-related tasks while giving tactile (touch) feedback. Each week will have different aims, progressively becoming more challenging. Sessions will be led by a clinical Exercise Therapist (biokineticist), starting with 5 minutes' warm-up, followed by 15-40 minutes of somatosensory activities, where you will be given short rest periods in between the exercises. The sessions end with 10 minutes cool-down and relaxing techniques. This group will not be allowed to wear any wristbands, which may provide them with tactile feedback.

Feedback-wristband

The feedback-wristband group will be asked to wear a wristband every day over eight weeks. If you are in the wristband group, you must wear the wristband during all times including whilst sleeping and bathing/showering/swimming. The feedback-wristband provides sensory feedback through touch sensation (tactile stimulation). This group will not be allowed to participate in any additional structured physical activity. You are allowed to continue your normal activities as you did during the eight-week baseline phase.

4. POTENTIAL RISKS AND DISCOMFORTS

The procedures used in this research project involve no serious risks. We will do all within our power to reduce possible risks. There is a possibility that you may experience a loss of balance or fall during some of the balance assessments. However, there will be a chair behind you and/or soft gymnastic mats will be placed around the testing area to prevent injury. You will be assessed away from obstacles and in a safe environment without distractions. You may also stop at any time if you feel that you cannot continue the activity. There might also be research assistants to assist the main researchers. Furthermore, you will be more than welcome to alert us in case you experience any problems or discomfort. If you are not able to contact us for some reason, you are advised to contact your family doctor or go to the emergency department of your local hospital.

Everyone involved in this project are competent and experienced in exercise testing and will not expose you to unnecessary risks or discomfort. A biokineticist is an exercise therapist who is affiliated with the Health Professions Council of South Africa (HPCSA).

Safety procedures are in place to deal with emergencies that may arise during the tests i.e. a first aid kit, as well as Netcare Stellenbosch (082 911) and/or Stellenbosch Medi Clinic (021 861 2000). We want to remind you that your participation is voluntary and that you are free to withdraw from the research at any time, with no prejudice or discrimination by Stellenbosch University or the researchers.

5. POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

If you complete the study, you will directly benefit by taking part in this study, by receiving a DVD balance training program for free. You will also be learning more about Parkinson's disease and will contribute to the pool of knowledge on ways how to improve quality of life and decrease the risk of falls in individuals with Parkinson's disease.

6. PAYMENT FOR PARTICIPATION

There are no costs involved to participate in this study. This is a research study and not part of a treatment or diagnosis of Parkinson's disease. Participation is voluntary and therefore you will not receive any payment by taking part in our study.

7. CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of storing personal information and results from testing on a computer with a password. This computer is located inside the Motor Learning Laboratory in the Sport Science Department and access to it is limited to the researchers.

If a research article is published, your name will not be mentioned and all personal information will be kept anonymous. Results will be given as averages, percentages, etc. of the entire group and no exceptions will be made.

8. PARTICIPATION AND WITHDRAWAL

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. If you gain any muscular injuries as well as fractures during the study or find out that you have other neurological

conditions (e.g. Diabetes, stroke) or either visual or vestibular problems you please inform the researchers. The researchers may withdraw you from this research or part of the research if circumstances arise which warrant doing so.

9. IDENTIFICATION OF INVESTIGATORS

If you have any questions or concerns about the research, please feel free to contact Dr Karen Welman [welman@sun.ac.za; 021 808 4733 or 082 098 5387] or Ms Tania Gregory [16057473@sun.ac.za; 082 3390 787] at the Sport Science Department of Stellenbosch University.

10. RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, contact Ms Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] at the Division for Research Development.

All efforts are made to ensure your safety during the balance tests. However, if you obtain a research-related injury the researcher is trained in first aid and able to assist you. You can contact Mr van Kerwel (wvankerwel@sun.ac.za) at the University of Stellenbosch for information on the issue of compensation and coverage of medical expenses in the event of a research-related injury.

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

The information above was described to _____ [*me/the subject/the participant]* by _____ [*name of relevant person]* in _____ [*Afrikaans/English/Xhosa/other]* and _____ [*I am/the subject is/the participant is]* in command of this language or it was satisfactorily translated to _____ [*me/him/her*]. _____ [*I/the participant/the subject]* was given the opportunity to ask questions and these questions were answered to _____ *[my/his/her]* satisfaction.

[I hereby consent voluntarily to participate in this study/I hereby consent that the subject/participant may participate in this study.] I have been given a copy of this form.

_____

Name of Subject/Participant

_____

Name of Legal Representative (if applicable)

_____ _____

Signature of Subject/Participant or Legal Representative **Date**

SIGNATURE OF INVESTIGATOR

I declare that I explained the information given in this document to _____ [*name of the subject/participant]* and/or [his/her] representative _____ [*name of the representative]*. *[H*e/she] was encouraged and given ample time to ask me any questions. This conversation was conducted in [*Afrikaans/*English/*Xhosa/*Other*] and [*no translator was used/this conversation was translated into* _____ by _____].

_____ _____

Signature of Investigator **Date**

Appendix G

Personal Information

Name:

Surname:

Age:

Gender:

Contact number (please indicate your preferred contact method):

Level of Parkinson's (Hoehn &Yahr Scale), if known:

When were you diagnosed with PD?

Most affected side: (Left, right, both)

Occupation (if retired, state previous):

Current medication; and duration of use:

Any adverse effects of medication:

Who is your caregiver:

Relationship of caregiver:

Time spent without caregiver:

Would your caregiver like to attend the exercises as well?

Household chores:

Leisure time activities:

Has your doctor given you approval to participate in this study?

Who is your doctor?

Would you mind if we contact him/her?
If not please provide us with his/her contact no.

* Afrikaanse vorms is ook beskikbaar.

Appendix H

Health Screening Form

Name: _____ Surname: _____

Date of Birth: _____

1. How often do you participate in physical activity or exercise?
   Times per week: _____ Duration: _____ Type: _____

2. Do you have a history of any of the following?

☐ Heart attack	☐ Coronary thrombosis	☐ Narrowing arteries
☐ High cholesterol	☐ High blood pressure	☐ Leaking valve
☐ Stroke	☐ Angina /Chest pains	☐ Other heart condition
☐ Rheumatic fever	☐ Known heart murmur	☐ Palpitations
☐ Recent operation	☐ Edema	☐ Breathing problems
☐ Low blood pressure	☐ Seizures	☐ Lung disease
☐ Fainting or dizziness	☐ Cancer	☐ Diabetes
☐ Intermittent claudication	☐ Unusual fatigue	☐ Pain in chest

   ☐ Other (please indicate):
   _____

3. Do you have a recent history of, or currently have, any joint / muscle injuries or pain?

☐ Neck	☐ Upper back	☐ Lower back	☐ Hip
☐ Thigh	☐ Knee	☐ Lower leg	☐ Ankle
☐ Foot	☐ Shoulder	☐ Elbow	☐ Wrist or hand

   ☐ Other (please specify:
   _____

4. Has your doctor previously indicated any other conditions that we should know of?
   _____

5. Are you colour-blind? ☐ Yes ☐ No

* Afrikaanse vorms is ook beskikbaar.

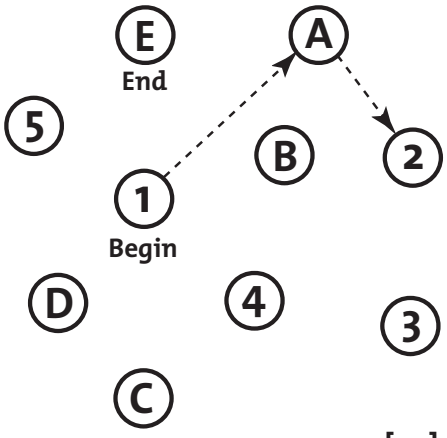
Appendix I

Montreal Cognitive Assessment (MoCA)

MONTREAL COGNITIVE ASSESSMENT (MOCA)

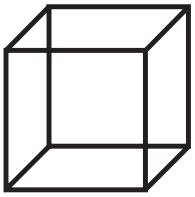
NAME :
Education : Date of birth :
Sex : DATE :

VISUOSPATIAL / EXECUTIVE



[ ]

Copy cube



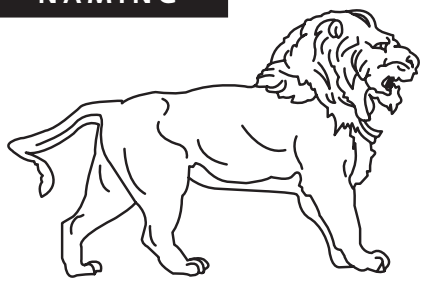
[ ]

Draw CLOCK (Ten past eleven)
(3 points)

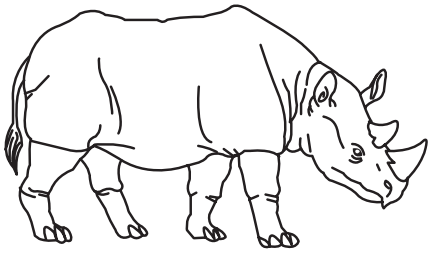
[ ] Contour [ ] Numbers [ ] Hands

POINTS ___/5

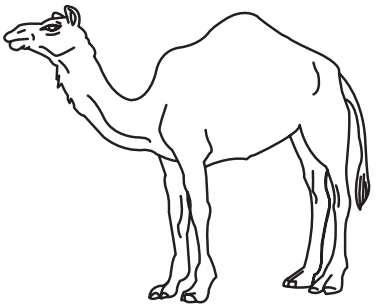
NAMING



[ ]



[ ]



[ ]

___/3

MEMORY

Read list of words, subject must repeat them. Do 2 trials. 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

 Version 7.0 www.mocatest.org

Normal ≥ 26 / 30

TOTAL ___/30

Add 1 point if ≤ 12 yr edu

Administered by: _____

Appendix J

Intrinsic Motivation Inventory (IMI)

Intrinsic Motivation Inventory (IMI)

Name: _____ Date: _____

For each of the following statements, please indicate with regard to the exercises you have performed in the programme how true it is for you, using the following scale:

1 2 3 4 5 6 7

not true somewhat true very true

	Statement	**Score**
1	I enjoyed doing this exercise programme very much	
2	I think I am pretty good at the exercises	
3	I put a lot of effort into the exercises	
4	I was very relaxed while doing the exercises	
5	I believe the exercises could be of some value to me	
6	The exercises were fun to do	
7	I am satisfied with my performance of the exercises	
8	I tried very hard while doing the exercises	
9	I was anxious while doing these exercises	
10	I think that doing these exercises is good for my health and fitness	
11	I thought the exercises were boring	
12	I think I was pretty skilled at the exercises	
13	I didn't put much energy into the exercises	
14	I felt pressured while doing the exercises	
15	I believe doing the exercises could be beneficial to me	
16	I thought the exercises were quite enjoyable	
17	These are exercises that I couldn't do very well	
18	It was important to me to do well at the exercise	
19	I did not feel nervous at all while doing the exercises	
20	I would be willing to do the exercises again as they have some value to me	

Thank you for taking part in our research

Appendix K

Medication and Affected Side

Table K.1: List of medication and affected side of sample.

EXP	Medication	AS	PBO	Medication	AS
1	Carbilev	right	1	Sinemet	left
2	Carbilev	left	2	Carbilev	right
3	Carbilev	right	3	Madopar	right
4	Carbilev	left	4	Carbilev	right
5	Carbilev	right	5	Carbilev	both
6	Azilect	left	6	Carbilev	both
7	Carbilev; Dissipal	right	7	Madopar; Pexola	right
8	Carbilev; Parkilyne	right	8	Madapor	both
9	Akineton; Pexola	right	9	Carbilev	both
10	Carbilev; Trepeline	right	10	Carbilev; Pexola; Sinemet	left
11	Parkilyne; Requip; Stalevo	both	11	Carbilev	both
12	Carbilev	left	12	Carbilev	links
13	None	right	13	Azilect; Pexola	both
14	Carbilev; Parkilyne	right			
15	Carbilev	left			
16	Carbilev	right			
17	Carbilev; Pexola	right			
18	Carbilev; Trepeline	right			
19	Azilect; Carbilev	both			
20	Azilect; Stalevo	both			
21	Dissipal	both			
22	Carbilev	left			
23	None	left			
24	Carbilev; Dissipal; Pexola	left			

Abbreviations: AS: Affected Side; EXP: Experimental group; PBO: Placebo group

Appendix L

Ethics Approval Letter

UNIVERSITEIT·STELLENBOSCH·UNIVERSITY
jou kennisvennoot • your knowledge partner

Approval Notice

Response to Modifications- (New Application)

25-Jun-2014
Gregory, Tania T

Proposal #: HS1041/2014
Title: Somatosensory training for postural control in independent-living individuals with Parkinson's disease.

Dear Ms Tania Gregory,

Your **Response to Modifications -** ***(New Application)*** received on **20-Jun-2014**, was reviewed by members of the **Research Ethics Committee: Human Research (Humanities)** via Expedited review procedures on **23-Jun-2014** and was approved.
Please note the following information about your approved research proposal:

Proposal Approval Period: **23-Jun-2014 -22-Jun-2015**

Please take note of the general Investigator Responsibilities attached to this letter. You may commence with your research after complying fully with these guidelines.

Please remember to use your **proposal number** (**HS1041/2014**) on any documents or correspondence with the REC concerning your research proposal.

Please note that the REC 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.

Also note that a progress report should be submitted to the Committee before the approval period has expired if a continuation is required. The Committee will then consider the continuation of the project for a further year (if necessary).

This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki and the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health). Annually a number of projects may be selected randomly for an external audit.

National Health Research Ethics Committee (NHREC) registration number REC-050411-032.

We wish you the best as you conduct your research.

If you have any questions or need further help, please contact the REC office at 0218089183.

Included Documents:
Research proposal_Gregory
DESC application
REC application form
Response to REC feedback
Revised documents
Questionnaires and scales
Informed consent 1
Revised research proposal
informed consent 2

Sincerely,

Clarissa GRAHAM
REC Coordinator
Research Ethics Committee: Human Research (Humanities)

Appendix M

Gait & Posture Manuscript Submittance Letter

Ms. Ref. No.: GAIPOS-D-15-00635
Title: Eight-week somatosensory training program improves mobility and fear of falling in individuals with mild to moderate Parkinson's disease Gait and Posture

Dear Ms Gregory,

Your submission entitled "Eight-week somatosensory training program improves mobility and fear of falling in individuals with mild to moderate Parkinson's disease" has been assigned the following manuscript number: GAIPOS-D-15-00635.

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: tg@sun.ac.za

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
Gait and Posture

Appendix N

Turnitin Report

Digital Receipt

This receipt acknowledges that Turnitin received your paper. Below you will find the receipt information regarding your submission.

Submission Author	Tania Gregory
Turnitin Paper ID (Ref. ID)	564072513
Submission Title	Somatosensory training for postural control in independent-living individuals with Parkinson's disease
Assignment Title	Turnitin Sandbox
Submission Date	30/08/15, 19:51
Similarity percentage	18%