

**Nordic Pole Walking, Gait Pattern and Postural Control in
Parkinson Disease**

by

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Abstract

Background: Gait impairments and postural deficits are very common in people with Parkinson Disease (PD), and also highly associated with fall risk and functional decline. Some evidence showed that in older adults, Nordic Walking (NW) could slow the progression of some gait impairments and increasing stride length and gait speed. Moreover, previous studies suggested that gait disturbances in PD are associated with less automatic gait performances and therefore gait requires more attention, as it is essential for regulation of postural balance. Further, research of this fact has very minimally been examined in PD population.

Purpose: The purpose of this study is to investigate whether Nordic walking can improve gait pattern in individual with PD after a 6-week training program, as well as determine the effect of performing a cognitive task while walking with and without the poles on gait characteristics.

Methods: Gait spatial temporal and kinetics data was collected with and without poles in 12 adults with PD (age: 61.58 ± 11.7 years; 9 male, 3 female; Hoehn and Yahr scale 1-3 stage; UPDRS III average: 11; the year of diagnosis: 6.72 years). Participants performed six 5m walking trials; 3 with poles and 3 without after 6-week training. Participants also performed four 90 seconds walking trials on a 25m pathway in four different conditions: NP (no poles) and no cognitive task, NW (Nordic walking) and no cognitive task, NP and

a cognitive task, NW and a cognitive task. For this latter part of the experiment, gait characteristics and trunk kinematics were quantified by using a 6 inertial sensor accelerometry system (APDM, Oregon, USA). As for the 5m tasks, gait spatial temporal and kinetics were collected with an eight cameras 3-dimensional motion capture system (Vicon, Oxford, UK) and 2 force platforms (Kistler, Winterthur, Switzerland). All variables were assessed using paired t-test to compare NW to conventional walking and two-way ANOVA to compare cognitive and pole conditions.

Results: When comparing NW to NP, the results showed significantly longer stride length, and larger single support time. The data also showed larger knee power generation during mid-stance as well as decreased power absorption at the knee during swing. Moreover, when assessing the effect of performing a cognitive task on gait, gait speed and cadence in both normal walking and Nordic pole walking was significant smaller when performing the cognitive task. The trunk frontal range of motion (ROM) and velocity were smaller compared NW to NP. When adding cognitive tasks, trunk frontal ROM and velocity were significantly smaller.

Conclusions: Based on the results, 16 self-directed sessions of NW can help improve certain gait spatial-temporal characteristics as well as some aspect of the gait pattern kinetics, especially at the knee. Moreover it seems that a 16 sessions (45mintues per

session) or even longer practice period is necessary for NW beginner, in order to gain perfect technique and restore gait to a more normal pattern than novice.

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Abbreviation:

PD: Parkinson Disease

MCI: Mild Cognitive Impairment

NW: Nordic Walking

NP: Normal Walking

STN-DBS: subthalamic nucleus deep brain stimulation

FOG: Freezing of Gait

MoCA: Montreal Cognitive Assessment

CHAPTER 1: Background

1.1 Background:

Parkinson's Disease (PD) is one of the most common neurodegenerative diseases. PD often happens in later life with about 1–2 % of the population over the age of 65 that have been diagnosed with PD. This goes up to 3% to 5% in individuals 85 years old or older (Forsaa et al., 2008). The most common motor symptoms in PD are bradykinesia, muscle rigidity, and resting tremor (Cole et al., 2010; McNeely et al., 2012; Nantel et al., 2012). However, postural balance and gait deficits are amongst the most important disabilities as they put individuals at high risk for fall (McNeely, et al., 2012). PD has also been associated with Mild Cognitive Impairments (MCI). MCI increase with the severity of the disease and has been reported as an independent predictor of dementia in PD (Verbaan et al., 2006).

Gait impairments and postural deficits are present in 40% of people living with PD, four or five years after the PD diagnosis and increases with disease severity (Forsaa et al., 2008). This is highly associated to risk for falls and loss of independence (McNeely et al., 2012). Gait abnormalities include decreased walking speed, shortened stride length and insufficient heelstrike (McIntosh et al., 1997). Furthermore, it was shown that stride timing variability was significantly greater in PD people who had a history of falling (Hausdorff et al., 2003). Other result showed that PD fallers walked more slowly than PD

non-fallers and with smaller steps (Cole et al., 2010).

Postural instability in people with PD leads to different gait deficits such as shorter steps and larger gait variability (Nantel et al., 2014; Moriss et al., 2000). While dopaminergic medication and subthalamic nucleus deep brain stimulation (STN-DBS) improve motor symptoms such as rigidity and tremors, their benefits on postural balance and gait are not as clear (Nantel et al. 2014; McNeely et al. 2012).

Deficits in attention and impairments in the executive function have been associated with postural instability and gait dysfunctions, thus related to high risk of falls (Joong-Seok Kim et al., 2013, Nantel et al., 2012). Gait variability, which has been reported to be larger in individuals with PD, increases when gait is combined with a cognitive task (Yogev et al., 2005). Individuals with PD also experience further reductions in step length and speed when engaged in dual task conditions (O'Shea et al., 2002). Furthermore, decline in cognitive functions and especially in the executive function has been reported as an independent risk factor for dementia, which makes it a major concern in the management of the disease (Verbaan et al., 2007). Individual of the Postural Instability and Gait Disturbances (PIGD) phenotype have been shown to be more at risks of developing cognitive deficits (Montero-Odasso et al., 2012, MCGOUGH et al., 2011). The underlying mechanisms leading to higher occurrence of MCI and dementia in individuals in the PIGD phenotype compared to the tremor dominant

phenotype are not known. However, it has been shown that neither the cognitive or gait and balance symptoms are clearly responsive to current treatment (dopaminergic medication and STN-DBS) (Nantel et al., 2012, Johnsen et al., 2009, Guehl et al., 2005). Therefore, there is an urgent need for investigating alternative solutions.

Growing evidence shows that people who engage in physical activity are more likely to have better functional mobility (Patel et al., 2006). Physical activity can also help reduce gait and balance deficits by improving gait stability, stride length and speed which are associated with lower risk of falling (Nadeau et al., 2013). There is a growing interest in Nordic Walking (NW) as the addition of the poles provide external support, which could be beneficial in individuals with PD and especially in those with balance and gait deficits. Indeed, pole walking has been shown to improve balance, and increase walking velocity in healthy adults (Willson et al., 2001, Dalton and Nantel, 2016). However, there are very few papers studying the effect of NW on gait and postural balance in individuals with PD. In this paper, our main objective is to assess whether walking with NW poles can provide additional support and help improving postural balance and gait pattern in individuals with PD.

1.2 Research Purpose:

The objective of the present study was to establish the effect of NW on: 1) spatial temporal variables such as gait speed, stride length, cadence, single support time, double support time, and power generation/absorption at the ankle, knee and hip joints as well as on the postural alignment of the trunk, and 2) to establish the cognitive load of walking with poles on these variables.

1.3 Variables:

Spatial-temporal gait characteristics, such as gait speed, stride length, cadence, single support time, and double support time, lower and upper limbs symmetry as well as range of motion and trunk alignment will be collected using both Vicon motion analysis system (Oxford, UK) and APDM inertial measurement units (Oregon, United States). Two force platforms (Kistler, Winterthur, Switzerland) used in concomitance with Vicon motion analysis will allow assessing kinetics of the lower extremity, moments of force, and power.

1.4 Hypothesis:

Based on our previous data in older adults showing improvement in some gait spatial-temporal characteristics and kinetic patterns (Dalton and Nantel, 2016), we

hypothesized that NW would lead to an improvement in gait spatial-temporal characteristics (i.e. an increase in gait velocity, stride length, cadence, and single support time, along with decreased double support time), as well as an improvement in gait kinetics profiles (i.e. increased power generation at the ankle, knee and hip) both on participants' most and less affected sides. Indeed, since the evolution of the symptoms in PD is asymmetrical, the legs have to be analyzed separately as it can lead to difference in movement performance (Louie et al., 2009). The most and less affected sides were determined by performing the Unified Parkinson's disease rating scale motor examination (UPDRS III), the Hoehn and Yahr scale as well as by asking participants which side is the most affected. Second, we hypothesized that combining gait with a cognitive task will lead to a decline in spatial-temporal variables when walking without the poles, and even more so when walking with the poles. Lastly, we expected to see an improvement in the regulation of the trunk movement in the anterior-posterior (a more upright position) and in the medial-lateral (smaller trunk ROM and maximal speed) directions in NW compared to NP.

1.5 Limitations:

The small number of participants included in this study limits the generalization of our results. Indeed, a larger sample size could have allowed us to compare the effect of walking with the poles according to the severity of the disease, which is not possible to

do here. However, based on previous data in older adults (Dalton and Nantel, 2016) we believe that the sample size proposed here is adequate to support our hypotheses.

Furthermore, our protocol did not include a pre-training gait analysis, which did not allow assessing the potential effect of the walking training program on the gait pattern when walking without the poles.

CHAPTER 2: Literature review

2.1 Parkinson's disease

According to Statistics Canada (2014.11.19 Statistics Canada), in 2014, 55,000 Canadians aged 18 or older living in private households reported that they had been diagnosed with PD. PD is more often diagnosed after the age of 50 years old. Therefore, in 2014 1%-2% individuals aged of 65 years old or more were living with PD. The average age at which these people had first experienced symptoms was around 64.4 years old, which led to a formal diagnosis approximately 1.9 years later. PD touches 12,500 residents of long-term residential care facilities, which represents 4.9% of this population (2014.11.19 Statistics Canada).

2.2 Most common motor symptoms and effect of medications on these symptoms

The most common motor symptoms in PD are bradykinesia, muscle rigidity, and resting tremor (Cole et al., 2010). Besides, people with PD also suffer from gait impairments and balance deficits, which increase the risk of falls. (Nantel et al, 2014; Buckley et al., 2008; Morris et al., 2000) and this increases with disease severity. Common treatments in Parkinson disease are subthalamic nucleus deep brain stimulation (STN-DBS) and dopaminergic medication treatment. Dopaminergic replacement medications can relieve motor symptoms, such as tremor and bradykinesia. If dopaminergic medication can

improve balance and gait pattern in some individuals, substantial impairments in balance and gait often remain (McNeely et al., 2012, Nantel et al., 2012). To this date, there is still no consensus on the effect of dopaminergic replacement medications on postural balance.

STN-DBS improves certain motor symptoms via non-dopaminergic connections to structures relevant for gait and balance (McNeely et al., 2012; Nantel et al., 2012). Some studies showed that muscle activation and the speed of movement were improved when on STN-DBS or medications (Vaillancourt et al., 2004). Looking at the effect of both medications and STN-DBS on postural stability, Nantel et al., (2012) showed that PD subjects with “PD-normal” balance became unstable on medications and return to normal after STN-DBS. However, subjects with “PD-abnormal” balance in quiet stance did not benefit from medication or DBS.

2.3 Gait and posture deficits in individuals with PD

2.3.1 Postural balance in Parkinson disease

Postural instability is a common motor symptom in PD that affects activities of daily living (Cole et al., 2010; Nantel et al., 2014). Postural instability and balance deficits increase with disease severity, putting individuals in the latest stages of the disease at high risk for falls. Postural instability has been reported both during quiet standing,

turning and functional task, such as turning, reaching for a glass on a shelf or rising from a seated position (Nantel et al., 2011; Morris et al., 2000, Kim et al., 2012, Mellone et al., 2016). The lack of flexibility in shifting postural responses and compensatory stepping, as well as adjusting motor responses to changing task demands, may all contribute to the high incidence of falls in people with Parkinson's disease (Boonstra et al., 2008).

2.3.2 Normal gait pattern

The average of walking speed for an adult is about 1.3-1.5m/s (Oberg et al., 1993). A complete gait cycle is defined as two steps, i.e. from the heel contact of one foot to the heel contact of the same foot and contains two main phases: the stance phase and the swing phase. The stance phase accounts for 60% of the gait cycle while the swing phase account for 40%. The percentage of the gait cycle spend in double support i.e. when both the feet are in contact with ground accounts for 20% of gait cycle, while the single support phase, i.e. when only one feet is in contact with the ground, accounts for about 80% of the gait cycle. The double support phase is considered stable, as the base of support defined by the feet on the ground is large compared to the base of support during the single support phase. In normal population, the gait pattern between the left and the right legs is considered symmetric (Sadeghi et al., 2000). However, gait asymmetry has been associated with gait speed and gait variability (Yogev et al., 2007) The forward motion during gait is regulated by the muscle power generation and absorption at the

ankle, knee, hip joints. According to Winter (1991), the power phases are defined as follow: A region of power absorption at the ankle during mid-stance (A1), and also concentric burst of plantar flexor (power generation) during pre-swing (A2). A2 is considered as the main power generation phase which contributes to the push-off of the foot against the ground to initiate the propulsion of the leg for the swing phase. At the knee, there is a region of positive power with knee extensor during loading response (K1). During mid-stance (K2), a region of positive power is found corresponding to concentric knee extensor. During pre-swing phase (K3), there is a power absorption, which is used for preventing from knee joint collapse. For the terminal swing phase (K4), the knee flexor absorbing energy from decelerating the swing leg. At the hip, during loading response (H1), there is a small region of power generation and during mid-stance (H2), the hip flexor controls the backward rotating thigh, and during the pre-swing phase (H3), hip flexor is generating energy to start the “pull-off” of the lower limb (Winter, 1991)

2.3.3 Locomotion in Parkinson disease

Individuals with PD are known to walk with short steps, narrow base of support as well as slow and shuffling gait or on the opposite, festination (Morris et al., 2001, Hass et al., 2012). They also exhibit forward-stooped posture as well as a reduction of range of motion at the upper limbs, predominantly on one side, which increases asymmetrical arm

swing (Hass et al., 2012). Gait in individuals with PD is also highly variable and asymmetric (Morris et al., 1994; Almeida et al., 2007). Some individuals of the PIGD phenotype can also develop freezing of gait, which has been described as feeling that your feet are glued to the floor when walking, making a turn, initiating walking or going through doorways (Plotnik et al., 2008). Previous to experiencing a freezing episode, freezers often show festination (rapid small steps), which increases to the point when they cannot even stop or turn around.

2.3.1 Coordination and gait symmetry

As the disease progresses, gait pattern in individuals with PD becomes more asymmetric, less rhythmic and more uncoordinated (Plotnik et al., 2008). These symptoms are even more important in individuals with FOG (Nantel et al., 2012; Plotnik et al., 2008). Morris et al (2001) reported that the stereotyped gait pattern seen in PD is caused by the progressive loss of flexibility and adaptability in their locomotion. This reduction in flexibility was also reported as an inability to coordinate interlimb movement (Dietz et al., 1995; Winogrodzka et al., 2005; Mahabier et al., 2013), mostly due to a failure in adequate supraspinal control (Mahabier et al., 2013). This inability to regulate interlimb coordination within and between the arms and legs was shown to become more prominent in more advanced stages of PD (Carpinella et al., 2007; Crenna et al., 2008).

2.4 Cognition in PD: Effect of dual tasking on postural balance and gait.

Previous results suggested that gait disturbances in PD were associated with the decreased activation of a cognitive network that comprises the parieto-occipital regions (Crémers et al., 2012). Several studies have also identified impaired cognitive functions as a factor associated with an increased risk of falls in people with PD (Paul et al., 2014). It has been shown that gait impairments are highly related to Mild Cognitive Impairments (MCI) (Yogev et al., 2007, Nantel et al., 2014). Executive function and visual spatial processing are important aspects of cognitive impairments in PD. In PD, deficits in these functions have been associated with larger gait asymmetry when gait is performed as a single task, but even more so when gait is performed as a dual task (Plotnik et al., 2011). Indeed, gait in individuals with PD is known to be less automatic, as they rely more heavily on cognition, which therefore increases gait asymmetry and risk of falls (Liu et al., 2011, O'Shea et al., 2002). Overall, the effect of dual tasking on gait in PD has been shown to reduce gait speed, stride length, swing times and arm swing as well as to increase stride time variability and swing time variability.

2.5 Nordic Pole walking

Mobility-related disabilities are common in the elderly. Roughly 30% of community-dwelling older adults fall each year. In order to prevent fall and other injuries caused by fall, exercise programs of varying intensity, frequency, and length, have been

shown to positively impact the physical capacity of older adults. Exercise program such as NW works on many components of health, including cardiovascular health, joint loading, posture, and strength, both for the upper and lower body. Some older adults are also under the impression that walking with poles provides increased safety over uneven terrain and reduce loading on the lower extremities. Indeed, as individuals become fatigued, they may employ greater upper arm forces to help absorb or generate energy (Willson et al., 2001). However, Jensen et al. (2011), showed no reduction in the knee joint compressive force, and velocity in older adults when using poles. Several reasons may lead to this result: the pole was not placed perpendicular to the ground, the participants' age and conditions were various, the load and velocity were hard to measure precisely. However, looking at young participants, (Willson et al., 2001) reached a different result and reported that walking with poles tended to increase walking velocity while reducing vertical knee joint reaction forces.

Few studies have investigated the effect of a NW training program in individuals with PD. Amongst them, Van Eijkeren et al., (2008) demonstrated that pole walking could be beneficial in this population. Using different functional tasks such as a 10 meters walk test, the 6-minute walk test and the get-up and go test, the authors showed that participants improved on these tests after a 6-week Nordic walking program. In another study, Reuter et al (2011) studied and compared the effect of three different interventions

on 90 participants. Participants were divided into three training groups according to the type of intervention: flexibility and relaxation program, normal walking and NW. The results showed that people with PD, who completed NW training, had a better posture and postural stability, and were faster in alternating movement compared to the other groups. However, the advantages of walking with poles still require further examination through extensive biomechanical gait and posture analyses. Furthermore the cognitive load of operating the poles should be investigated, especially in population at high risk for falls.

To our knowledge, the effect of NW on gait pattern and trunk stability was never assessed in individuals with PD. As NW could have a beneficial effect on gait pattern in PD and could potentially be used in gait rehabilitation protocol, we believe that this subject need to be further investigated.

CHAPTER 3: Methodology

3.1 General methods:

Based on our results in a previous study investigating the effect of Nordic Walking on gait pattern in older adults (Dalton and Nantel, 2016), participants had six weeks to familiarize themselves with walking with the poles. Soon after, they were asked to come to the lab (200 lees university of Ottawa) to participate in a ~90min long gait analysis. During this session, gait spatial temporal and kinetics data were both collected with and without poles.

3.2 Design:

A laboratory test study design was performed to quantify postural and gait variables amongst participants through comparison of normal walking and Nordic poles walking. According to Herfurth et al (2015), gait velocity and step length can predict the outcome of NW training. Then the variables being examined in the research protocol included:

Motion Analyses:

Vicon and APDM:

The gait parameters we quantified were:

- Spatial-temporal gait parameters: gait speed, stride length, cadence, single support time, and double support time.

- Trunk postural alignment in the sagittal, frontal and transverse plane of motion.

Vicon:

- Kinematics (ankle, knee, hip range of motion) of the lower extremity.
- Power at the ankle, knee and hip joints.

3.3 Participants and recruitments:

Fourteen participants were recruited from the Ottawa Community for this study. From this number thirteen completed the protocol. Data from 1 participant was not included in the data analysis because the participant presented cognitive impairments that prevented him from understanding the instruction (MoCA score: 21).

Inclusion Criteria: To be included in the study, participants had been formally diagnosed with Parkinson's disease and presented with symptoms that include slowness of movement, muscle rigidity, resting tremor and with or without freezing of gait. Participants had to be ambulatory, therefore in the stage I – III according to the Hoehn and Yahr scale. Participants didn't have any neurological conditions other than PD or any injuries/surgeries to lower extremity or shoulders that could interfere both with gait and control of the poles

Exclusion Criteria: Participants were excluded from the study if they present cognitive impairments that could interfere with their understanding of the protocol and ability to manage the poles when walking. Therefore, participants presenting with a Montreal Cognitive Assessment (MoCA) score < 26 , were excluded from the study.

The most and less affected sides were determined on the basis of the UPDRS III , the Hoelh and Yahr scale score as well as by asking participants which side was the most affected by the disease.

Prior to recruitment and study commencement, approval of the study by the University of Ottawa Research Ethics Boards was completed. After being fully informed of the purpose, potential risks, and benefits of the study as well as being given the opportunity to ask questions, participants were required to provide written informed consent to be a part of the study.

3.4 Procedure and data collection:

All participants were asked to complete an independent 6-week long training, three times per week, for about 30-45 minutes/session. After completing the training, participants were asked to come to the *Biomechanics and motor performance laboratory* at the University of Ottawa (Lees campus, room E053) for testing.

Information regarding the Nordic walking program was provided prior to the familiarization process. This allowed participants to ask questions and familiarize themselves with what was expected of them through this process. During this 45 minutes session, participant received instruction on the proper pole walking technique.

Participants completed the 6 weeks initiation on their own. However, participants were asked to fill-out a logbook after each session to assure that they were following the practice schedule. Participants also received weekly phone calls from one of the members of our team to allow participants to express any concerns or ask questions about their practice.

After participants became familiar with Nordic poles walking, they were asked to take part in two gait assessments.

1. Motion analysis with the Vicon system (Vicon, Oxford, UK)

During the testing, each participant would first be asked to walk along a 5 meters walkway at a self-selected speed, with and without walking poles, for 3 trials per conditions. The order of the trials was randomized. Participants were unaware of the force platforms placement on the walking pathway to assure natural gait. Therefore, they were encouraged to perform 3 to 5 gait initiation practice trials, to assure the appropriate

placement of the feet on the force platforms. Indeed, to be considered a “good trial”, participants needed to make full contact with both feet on each of the force platform.

2. Accelerometry based motion analysis with the APDM system (Oregon, United States)

Each participant was also asked to complete four trials of a 3 minutes walk test (Willson et al., 2001; Reuter et al., 2011), in order to assess the gait variables over a longer period of time. Participants completed four conditions as follow:

Condition1. Normal walking

Condition 2: Normal walking while completing a category task

Condition 3: Nordic Pole Walking

Condition 4: Nordic Pole Walking while completing a category task

The category task consisted of a verbal fluency task, in which participants had to name as many items as possible in 25 seconds in a preselected category. Categories were as follow: cities, countries, animals, colors, vegetables, sports, fruits, beverages, jobs, and all the answers were recorded during testing.

3.5 Data Collection:

Vicon analysis

All motion was recorded at a sampling frequency of 200 Hz using a reflective infrared motion capture system with eight 3-dimensional cameras (Vicon, Oxford, UK). We quantified the kinetic parameters, postural alignment and gait spatial-temporal measures through this equipment. Before data collection, a dynamic calibration of the motion capture system was performed by using a 3-marker wand, waved through the capture volume in order to help with the reconstruction of the 3-dimensional positions of the reflective markers. Second, a static calibration trial was performed by using a 4 marker L-frame to set the capture volume and the global coordinate system. After all the steps were finished, we started a static trial as a baseline of the dynamic trial.

Gait spatial-temporal parameters measured with the Vicon system (Vicon, Oxford, UK) required some basic anthropometric measurements including height, weight, inter-ASIS distance, leg length, knee width, ankle width, shoulder offset, elbow width, wrist width, and hand thickness. Those measurements were then incorporated into the full body plug-in-gait model (Vicon, Oxford, UK). This model includes 39 reflective markers (14mm), placed at specific anatomical landmarks including: second metatarsals, lateral malleoli, calcanei, left and right mid-shank, lateral femoral condyles, left and right mid-thigh, ASIS, PSIS, T10, C7, right back, clavicle, sternum, acromion processes, left and right mid-humerus, lateral epicondyles, left and right mid-forearm, medial and lateral wrists, second metacarpals, anterior-lateral head, and posterior-lateral head. Marker

trajectories were filtered using a fourth order, zero lag, Butterworth filter with a cut-off frequency of 10 Hz.

Kinetic data was also collected by using 2 Kistler force platforms (Kistler, Winterthur, Switzerland), collecting at a frequency of 1000 Hz. This allowed for quantification of the ground reaction forces and lower extremity joints moments of force and power using the Newton-Euler inverse dynamic method.

A static participant calibration was taken before the testing, Thirty-nine reflective markers (14mm) were placed at specific anatomical landmarks including: second metatarsals, lateral malleoli, calcanei, left and right mid-shank, lateral femoral condyles, left and right mid-thigh, ASIS, PSIS, T10, C7, right back, clavicle, sternum, acromion processes, left and right mid-humerus, lateral epicondyles, left and right mid-forearm, medial and lateral wrists, second metacarpals, anterior-lateral head, and posterior-lateral head. Participants were standing upright, with arms up laterally, palm facing forward. Participants were asked to stand still for 3-5 seconds until the static calibration was done. The static calibration gave the reference of each participant's model in Vicon, which was used for the further analysis.

Each trial was then collected and exported as an ASCII file to a Microsoft Excel spreadsheet. Based on work by Winter (1991) reporting muscle power generation and absorption bursts occurring during the gait cycle (e.g. A1, A2, K1, K2, etc.), macro functions were written to extract peak power and moment of force values from the filtered data.

Using the inverse dynamic, joint moment of force are the product of the inertia (kgm^2) by the angular acceleration (rad/s^2) while joint power is the product of the moment of force (in Nm) by the joint angular velocity (rad/s). After extracting the peak value of each trials, all the peaks' (A1,A2,K1,K2, etc) mean and standard deviation were calculated in excel.

APDM analysis:

Postural alignment and spatial-temporal gait parameters were quantified by using a 6-monitor accelerometer system (APDM, Oregon, United States). The Mobility Lab Software is used to configure the hardware and record the movement data. The wireless Access Point allows for wireless communication between the computer and the movement monitors. The monitors were placed on the left and right wrists, the left and right ankles, the lumbar spine, and the trunk. Spatial-temporal measures (e.g. gait speed) and postural alignment were measured through analysis of trunk, lumbar, and extremity accelerations. Besides, the stability of the trunk was measured by testing the differential

between the trunk accelerations and the lumbar accelerations. The accelerometers were collecting at a frequency of 128Hz.

After testing, all the trials were transfer to analyze in polygon (Vicon) and Matlab (APDM).

3.6 Statistical analysis:

For the motion analysis (spatial-temporal and kinetics) with the Vicon system, participants performed two walking conditions: without and with poles. Mixed models were performed for the less affected side and the most affected side. Indeed since the evolution of PD is asymmetrical, the legs have to be analyzed separately as it can lead to difference in movement performance (Louie et al., 2009).

For the APDM data: the two-way repeated measures analysis of variance (ANOVA) were performed on each of the dependent variables to determine statistical significance (with / without poles; with / without cognitive task).

Statistical significance was set at $p < 0.05$. If Mauchly's Test of Sphericity was violated (i.e. $p < 0.05$), a Greenhouse-Geisser correction was performed. If statistical significance

was found with the ANOVA, Tukey's post-hoc analysis was performed to determine where the significance lay.

CHAPTER 4: Research article

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Nordic walking improves gait stability and power profiles at the knee and hip joints in Parkinson's disease

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Running title: Nordic walking, gait pattern and postural control in Parkinson disease

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4.1 Abstract

Gait impairments are strongly associated with functional decline in Parkinson's disease (PD). Nordic Walking (NW) has been shown to improve stride length and gait speed in older adults. In this study, we investigated the impact of Nordic walking (NW) on gait patterns in individuals with PD.

Following a 6-week self-directed training program, twelve participants with PD (age: 61.58 ± 11.7 , 9 male, 3 female) and twelve healthy older adults (mean age: 68 ± 6.4 year, 8 female, 4 male) performed a gait assessment during NW and without poles (NP). Gait was assessed using 8-Vicon cameras and two force platforms. Gait spatial-temporal characteristics and kinetics profiles were compared between poling conditions and between the groups.

Results showed larger knee power generation with the knee extensor muscles (K2) on the most affected leg in NW compared to NP ($P=0.01$). On the less affected side, larger power absorption with the knee extensor muscles was found during pre-swing (K3) in PD compared to older adults in both NP and NW ($P=0.01$). Both legs showed larger hip power absorption (H2) and generation (H3) in PD compared to older adults when walking with and without the poles ($P \leq 0.05$). NW also resulted in longer stride length and single support time ($P < 0.01$) compared to NP.

A 6-week NW program improves gait spatial-temporal characteristics and power profiles at the knee joint, both on the less and most affected sides in individuals with PD. NW could be useful in gait rehabilitation in PD.

Keywords: *Nordic walking, gait, Parkinson disease, joint power, postural stability*

4.2 Introduction

Parkinson's disease (PD) is one of the most common neurodegenerative diseases. PD touches approximately 1–2 % of the population over the age of 65 and 3% to 5% in individuals 85 years old or older (Forsaa et al., 2008). Bradykinesia, muscle rigidity, and resting tremor are among the most common motor symptoms in PD. However, postural balance and gait deficits are known to lead to major disabilities and loss of independence (McNeely, et al., 2012). Gait deficits include decreased walking speed, shortened stride length and higher cadence as well as larger stride time variability, which is associated with history of falling (Lim et al., 2007; Atkinson et al., 2007). Biomechanical gait analyses showed a reduction in power generation with the plantarflexors during the push-off phase (A2) and with the hip flexors during the pull-off phase (H3) (Lim et al., 2007; Sofuwa et al., 2005; Morris et al., 2001, Winter et al., 1991). Modification of the power profiles at the knee joint were also reported and associated with the reduction of power generation at the ankle joint (Sofuwa et al., 2005).

Growing evidence shows that physical activity in individuals with PD can improve gait stability, stride length and gait speed and therefore help reduce gait and balance deficits as well as risk of falling (Nadeau et al., 2013). A recent study has shown not only improvements in the spatial-temporal aspects of gait, but also in power profiles in older adults following a Nordic walking (NW) training program (Dalton and Nantel, 2016). Specifically, a 6-week self-directed NW training program improved power profiles at the hip and knee joints in healthy older adults. In individuals with PD, NW was shown to lead to larger improvements in walking speed and functional mobility compared to a free walking program (Monteiro et al., 2016). However, to our knowledge no studies investigated the impact of NW on gait power profiles to explain the underlying improvements in gait pattern in individuals with PD.

The main objective of this study was to assess whether NW can provide additional support and help to improve postural stability and gait pattern in individuals with PD. We aim to determine the effect of NW on gait spatial-temporal characteristics (i.e. gait velocity, stride length, cadence, and double and single support phases) and kinetics (i.e. lower extremity joint power generation and absorption) at the ankle, knee and hip. Another objective is to compare gait patterns between older adults and individuals with PD.

4.3 Methods

4.3.1 Participants

Twelve adults with PD (mean age: 61.58 ± 11.7 years, 9 male, 3 female; Hoehn and Yahr scale 1-3 stage; UPDRS III: 11 ± 5.40 ; disease duration: 6.72 ± 3.99 years) and twelve healthy older adults (mean age: 68 ± 6.4 year, 8 female, 4 male) were included in this study. PD participants and older adults were recruited from the Community. To take part in the study, PD participants had to have been formally diagnosed with PD. Participants had to be ambulatory, therefore in the stage I – III according to the Hoehn and Yahr scale. Participants were excluded of the study if they had any neurological conditions other than PD or any injuries/surgeries to the lower extremity or shoulders that could have interfered with their gait pattern or their ability to use the poles. Participants in the control group were screened for any history of injury, surgery or neurological conditions that could have affected their gait pattern. The study was approved by our institutional review board and each participant provided their written informed consent prior to study commencement.

4.3.2 Nordic Walking Instruction

During the first visit, each participant was provided with a set of Nordic walking poles. Participants were given a 45-60 minutes tutorial on how to use the poles. After adjusting the poles to an optimal length relative to their height, technique instructions were as follows: 1) stand tall, 2) place the pole tip in front of the toes, 3) place the elbow and

forearm next to the body, and 4) lengthen the poles so the elbow forms a 90° angle. Poles were then securely tightened and boot tips were appropriately angled backward. Participants were then asked to practice with the instructor and were given feedback on their technique.

After the tutorial, participants completed an independent 6-week NW training program, three to four times per week for 30-45 minutes per session. Completion of a minimum of 12 sessions out of 16 was required for participants to be included in the statistical analyses. This was accounted for through a physical activity logbook, completed by each participant following each session. All participants completed at least 12 sessions and therefore data from all participants were included in the study. Each session included: a 5-10 minutes warm-up involving dynamic movements (e.g. leg swings) followed by 45 minutes of NW, and a 5-10 minute cool down involving static stretches.

4.3.3 Procedure and data reduction

For the gait assessment, each participant was asked to perform 6 walking trials; three NW trials and three trials without poles, at a self-selected pace along a 5-metre walkway. Thirty-nine reflective markers were positioned at specific anatomical landmarks according to the full body Plug-in gait model (Vicon, Oxford, UK). Two force platforms

(Kistler, Winterthur, Switzerland) embedded in the walkway were used to collect gait kinetics. Gait kinematics and kinetics were recorded at a sampling frequency of 1000 Hz. Joint power profiles were normalized by the bodyweight to facilitate comparison between participants. Analog data was filtered using a zero lag fourth-order Butterworth filter with a cut-off frequency of 10 Hz. Marker trajectories were filtered using a Woltring filtering routine with a 15mm predicted MSE value.

4.3.4 Statistics

A mixed Analysis of Variance model was used to determine differences between controls and PD as well as to determine the within group effect of NW on stride length, gait speed, single support time, double support time, cadence as well as on joint power profiles at the ankle, knee and hip. Mixed models were performed for the less affected side and the most affected side (Louie et al., 2009). Level of statistical significance for all tests was set at $P < 0.05$ and Tukey procedures for multiple comparisons were used when needed.

4.5 Results

At the knee joint, we found main effects for both groups and conditions (Table 1 and Table 2 respectively). Comparisons between groups showed a main effect in power absorption with the knee extensor muscles (K3). On the less affected side, PD participants had larger K3 ($F_{1,21} = 28.50$, $P < 0.01$) both in NP ($P < 0.01$) and NW ($P < 0.01$) conditions compared to older adults. On the most affected side, individuals in the PD

group showed larger knee power absorption than controls ($F_{1,21}=4.802$, $P=0.04$) when walking without poles ($P=0.05$) and a trend was found when walking with the poles, ($P=0.067$). We also found a main effect for poles in K3 within PD participants (Fig 1). On the less affected side, K3 showed significantly smaller power absorption in NW compared to NP ($F_{1,21}=6.983$, $P=0.015$) ($P=0.037$). No statistically significant changes were found for K3 on the most affected side within PD. A similar main effect for pole condition was found in the control group ($F_{1,11} = 12.656$, $P = 0.004$), with significantly smaller K3 in NW compared to NP.

We found a main effect for condition for knee power generation with the knee extensor muscles (K2), on the most affected side within PD ($F_{1,21}=7.747$, $P=0.011$). Results showed significantly larger power generation during NW compared to NP ($P=0.01$). No statistically significant changes were found for K2 on the less affected side.

Gait pattern at the hip joint also showed a main effect for groups. Hip power absorption (H2) ($F_{1,20} = 4.856$, $P=0.039$) and generation (H3) ($F_{1,20} = 8.165$, $P=0.01$) with the hip flexor muscles on the less affected side, were larger compared to older adults when walking with poles ($P < 0.05$). Trends were also found for H2 ($P=0.066$) and H3 ($P=0.08$) when walking without poles. In control group, a main effect was found for pole conditions ($F_{1,11} = 7.003$, $P = 0.023$). Peak hip power generation by the hip flexors at H3 was significantly smaller NW compared to NP.

Moreover, within PD group, a trend was found at push-off (A2) on the most affected side. PD participants showed larger ankle power generation (A2) in NW compared NP ($P=0.07$). No significant differences were seen on the less affected side.

Gait spatial-temporal characteristics did not show main effect for groups ($F_{1,42}=0.008$, $P=0.929$), but did revealed main effect for pole conditions, Table 3. Within the PD group, stride length ($P=0.001$) and single support time ($P=0.003$) were longer in NW condition compared to NP condition. Cadence was significantly slower in NW compared to NP ($P=0.004$). Within the control group, a significant main effect for pole condition was found ($P = 0.006$), with NW resulting in significantly longer stride length and smaller single support time compared to NP.

4.6 Discussion

The present study aimed at determining if walking with poles after a self-directed 6-week NW familiarization training program can improve gait patterns in individuals with PD. Our results showed that walking with NW poles led to faster gait speed and larger stride length and that these changes may be due to improvements in power profiles at the knee joint in both the most affected and the less affected legs.

Nordic walking improves kinetics profiles at the knee joint

When walking with the poles, individuals with PD had larger power generation at K2 on the most affected side compared to walking without poles. This concentric contraction with the knee extensors moves the center of mass upward to allow toe clearance of the contralateral leg during the swing phase (Winter 1991). The larger K2 phase in individuals with PD when walking with poles could allow for safer clearance of the toes off the ground and therefore reduce risk of stumble and loss of balance. The additional support provided by the poles, as the base of support widens and the arms also contribute to the support of the bodyweight, could allow participants to be more stable and thus improve power generation on their weaker leg.

Differences between and within groups were also seen on the less affected side. Prior to swing phase in both NP and NW conditions, individuals with PD had larger power absorption with the knee extensor muscles (K3) compared to older adults. This eccentric contraction is used to prevent the knee joint from collapsing during the push-off phase at the ankle joint (A2) and to prepare for the knee extension during the swing phase (Winter 1991). Larger absorption with the knee extensor muscles is generally associated with an increased energy generation with plantarflexors during push-off (A2) (Judge et al., 1996, Winter 1991). To the contrary to an improvement in A2, previous studies reported a smaller power generation with the plantarflexors in individuals with PD (Sofuwa et al., 2005, Morris et al., 1999, Švehlík et al., 2009). Furthermore, Sofuwa et al. (2005) suggested that the reduced ankle power generation at push-off in PD could be responsible

for the reduction in knee power absorption in people with PD. Probably due to large inter-subject variability in our PD group, the A2 power burst was not significantly smaller compared to the control group. Our results suggest that the larger absorption in PD may allow enhancing postural stability during the push-off phase. Indeed, increasing stability during the push-off phase is of importance as participants are then transitioning into the swing phase with the less affected leg, and therefore transferring all the bodyweight on the weakest leg for the single support, which would then increase the risk for falls (Latt et al., 2009, Sofuwa et al., 2005).

However, in individuals with PD, K3 power absorption burst were significantly smaller when walking with the poles compared to walking without the poles. It is possible that the additional support provided by the poles increased their postural stability and allow participants to reduce the contribution of the knee extensor prior to transitioning from the double to the single support phase on their most affected leg. The longer time spent in single support phase when walking with the poles supports this hypothesis. Furthermore, when walking with the poles, muscles in the arms, shoulders and back also contribute to the bodyweight support. Therefore, this redistribution of the bodyweight on three limbs could provide a more stable base of support during the single support phase on the most affected leg. However, the current protocol does not allow verifying this hypothesis, as the energy transfer between the legs and the arms was not assessed.

Large contribution of the hip flexor muscles to the forward progression in individuals with PD

When walking with the NW poles, individuals with PD had significantly larger hip power absorption (H2) at mid-stance and generation (H3) during the swing phase compared to older adults. Two major strategies are used to move forward; the push-off strategy using the plantarflexors (A2) and the pull-up strategy that uses the hip flexors to pull the leg up and forward (H3). The pull-up strategy has been described as a compensatory strategy to overcome the lack of power generation in A2 in populations such as older adults and people with motor deficits, (Winter 1991; Dalton et al., 2016; Judge et al., 1996, Decker et al., 2003, Jonkers et al., 2008). Thus, the larger H3 power generation in PD may have been used to swing the leg and more efficiently move forward. As there were no differences between the pole conditions in PD, this strategy seems to be used as an overall compensation strategy in PD rather than an effect of walking with the poles.

However, within PD group, a trend was found at push-off (A2) on the most affected side when walking with the poles compared to without the poles. Dalton and Nantel, (2016) reported a non-significant increase in A2 during the push-off phase when NW and suggested that NW could therefore be used to enhance the contribution of the plantorflexors to the forward progression. In individuals with PD, the larger power generation when walking with the poles suggests that increasing postural stability allows

improving power generation on the weaker leg. This could have interesting implication for the development of gait rehabilitation programs in PD.

The small number of participants included in this study limits the generalization of our results. Indeed, a larger sample size could have allowed us to compare the effect of walking with the poles according to the severity of the disease. Furthermore, our protocol did not include a gait analysis prior to the training, which does not allow assessing the potential effect of the walking training program on the gait pattern when walking without the poles. This should be further investigated.

4.7 Conclusion

After a 6-week self-directed training program, walking with the NW poles resulted in improvement in gait spatial-temporal characteristics, and power profiles on both the less and more affected side in individuals with PD. Furthermore, the longer time spent in single support phase suggested an improvement in postural stability when walking with the poles. Overall, NW improved power generation at the knee and ankle on the weaker leg, while it decreased power absorption at the knee on the stronger side. Our results suggest that NW could be a relevant tool to use in gait rehabilitation, as the additional external support provided by the poles could help gradually modifying and regaining a more normal gait pattern.

Table and figure

Table1. Peak sagittal power generation/absorption at the ankle (A1-2), knee (K1-4) and hip (H1-3) for the PD and older adults groups when walking with and without the poles

Power W/kg	Walking without poles			Walking with poles		
	PD	PD	Control	PD	PD	Control
	most affected	less affected		most affected	less affected	
A1	-1.02(0.29)	-0.96 (0.36)	-1.02 (0.25)	-1.07 (0.29)	-1.05 (0.29)	-1.11 (0.44)
A2	3.07(0.91)	3.19 (0.86)	3.57 (0.78)	3.23 (1.00)	3.18 (0.93)	3.50 (0.91)
K1	-1.64 (0.62)	-1.67 (0.69)	-1.69 (0.49)	-1.59 (0.69)	-1.52 (0.50)	-1.66 (0.63)
K2	0.87 (0.35) ‡	1.03 (0.33)	0.76 (0.39)	1.05 (0.41)	1.09 (0.39)	0.88 (0.45)
K3	-2.31 (1.22)*	-3.12 (0.96)* ‡	-1.47(0.47)‡	-2.35 (1.52)	-2.86 (0.86)*	-1.39 (0.48)
K4	-1.68 (1.03)	-1.61 (0.42)	-1.90 (0.52)	-1.49 (0.70)	-1.63 (0.54)	-1.76 (0.60)
H1	1.33 (0.56)	1.73 (0.94)	1.36 (0.49)	1.45 (0.64)	1.66 (0.73)	1.21 (0.49)
H2	-1.28 (0.57)	-1.43 (0.43)	-1.08 (0.43)	-1.34 (0.47)	-1.50(0.48)*	-1.06 (0.44)
H3	1.81 (0.74)	2.13 (0.40)	1.67(0.51)‡	1.79 (0.84)	2.10 (0.42)*	1.50 (0.47)

*Significantly different from Control group at $P<0.05$

‡ Significantly different from NW at $P<0.05$

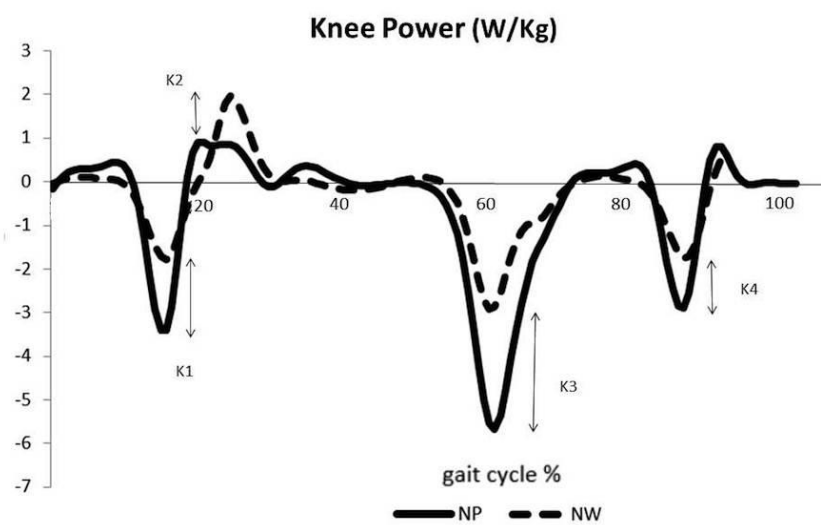
Table 2. Mean and standard deviation of the spatial-temporal gait characteristics comparing walking trials with poles (NW) and without poles (NP) in PD.

Outcomes	Walking without poles		Walking with poles	
	PD	Controls	PD	Controls
Stride Length (m)	1.34 (0.16)*	1.34(0.22)*	1.42(0.16)	1.42(0.19)
Gait velocity (m/s)	1.27 (0.19)	1.27(0.22)	1.31(0.19)	1.27(0.21)
Cadence (step/min)	112.25 (10.57)*	112.53(8.70)	107.62(10.01)	106.31(7.82)
Double Support (s)	0.29 (0.07)	0.24(0.06)	0.30 (0.07)	0.25(0.06)
Single Support (s)	0.40 (0.04)*	0.40(0.03)*	0.43 (0.05)	0.42(0.02)

*Significantly different from NW at $P < 0.05$

Figure 1. Peak knee power profile (W/Kg)

Peak sagittal power generation/absorption knee (K1-4) in the PD group when walking with (NW) and without the poles (NP)



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CHAPTER 5: Results

The data presented in this section concerned only the data collection made with the accelerometry system. For results from the motion analyses, refer to the manuscript in Chapter 4.

No significantly difference was found for moment of force in ankle, knee and hip, please see Table 2.

5.1 Spatial-Temporal Gait Analysis

APDM: Results of gait spatial temporal are reported in Table 3

We found differences in spatial-temporal gait characteristics when comparing walking with and without poles during the 90 seconds walking trials. The statistical analyses showed an effect of adding a cognitive task on gait speed ($F_{1,44}=13.777$, $P=0.008$), with gait speed decreasing both in NP ($P<0.01$) and NW conditions ($P<0.01$). Nothing was found between pole conditions. The same effect of was found for cadence ($F_{1,44}=5.371$, $P=0.054$), which was smaller with the addition of the cognitive task, both in NP ($P<0.05$) and NW ($P<0.05$). We found effects for both pole conditions ($F_{1,44}=12.385$, $P=0.010$) and the cognitive task ($F_{1,44}=6.265$, $P=0.041$) on stride length. Stride length was significantly smaller with the addition of the cognitive task both in NP ($P=0.013$) and NW ($P=0.012$). However, stride length was longer in NW compared to NP both without ($P=0.005$) and with ($P=0.003$) the cognitive task. Double support time percentage was found significantly different when adding cognitive task ($F_{1,44}=13.005$, $P=0.017$). Double

support time percentage was higher both during NP ($P=0.034$) and NW ($P=0.063$). A trend for increased gait cycle time was found with the addition of the cognitive task ($P=0.07$) during NP.

5.2 Postural (Trunk) Analysis: Data of trunk range of motion and velocity are reported in Table 4

For the trunk range of motion (ROM), the statistical analyses revealed a significant reduction in trunk frontal range of motion when walking with the poles compared to without the poles ($F_{1,28}=18.075$, $P=0.004$), both without cognitive task ($P=0.012$) and with cognitive task ($P=0.005$). Moreover, frontal ROM was found significantly larger in the NP condition with the addition of the cognitive task ($P=0.017$), this effect of the cognitive task was not seen in NW ($p=0.57$). The same significant effect of poles was seen for trunk frontal velocity ($F_{1,28}=45.985$, $P<0.001$), both without ($P=0.001$) and with cognitive task ($P=0.001$). A significant effect of cognition was seen for trunk horizontal ROM ($F_{1,28}=5.637$, $P=0.049$), with larger ROM in NP ($P=0.005$). However, no difference was found in NW condition ($P=0.357$). No significant effect was found for trunk ROM or velocity in the sagittal plane.

CHAPTER 6: Discussion

The present study determined the effectiveness of Nordic walking poles towards improving gait pattern in people with PD specifically spatial-temporal characteristics and the lower limb kinetic pattern profiles, as well as postural alignment. The objective of the present study was to establish the effect of NW on: 1) spatial-temporal variables such as gait speed, stride length, cadence, single support time, double support time, and power generation/absorption at the ankle, knee and hip joints as well as on the postural alignment of the trunk, and 2) to establish the cognitive load of walking with poles on these variables.

We hypothesized that NW would lead to an improvement in gait spatial-temporal characteristics (i.e. an increase in gait velocity, stride length, cadence, and single support time, along with decreased double support time), as well as an improvement in gait kinetics profiles (i.e. increased power generation at the ankle, knee and hip both on the most and less affected sides). Second, we hypothesized that combining a cognitive task would lead to a decline in spatial-temporal variables when walking without the poles, and even more so when walking with the poles. Lastly, we expected to see an improvement in the regulation of the trunk movement in the anterior-posterior (a more upright position) and in the medial-lateral (smaller trunk ROM and maximal velocity) directions in NW compared to NP.

Our results showed that NW led to faster gait speed, longer stride length and time spent in single support both during short and longer duration walking trials. According to the gait kinetic analysis, these changes may be most likely due to improvements in power profiles at the knee joint in both the most affected and the less affected sides. Walking with the poles also led to a reduction in trunk frontal ROM and velocity, which suggests that individuals with PD were more stable. Regarding the cognitive load of walking with the poles, while the addition of the cognitive task had a negative effect on gait spatial-temporal characteristics in both the NP and NW condition, this effect did not further increased in the NW condition. Furthermore, it did not negatively affect the trunk postural motion, which suggests that the cognitive load of NW can be sustained in individuals with PD. Therefore, the overall improvement in gait spatial-temporal characteristics, knee kinetics, trunk frontal ROM and velocity indicates that NW could be a useful tool in gait rehabilitation in individuals with PD.

6.1 Spatial-temporal and posture analysis

6.1.1 Nordic walking improves gait spatial-temporal variables and postural alignment

The addition of the poles, both during the longer and shorter gait trials led to similar improvement in gait spatial-temporal characteristics. NW increased gait speed and as a result it increased stride length and single support time and decreased cadence compared

to walking without poles. This is similar to results by Reuter et al. (2011), who compared the effect of three different intervention programs on mobility in people with PD. Participants were randomly assigned to either the flexibility and relaxation program, the normal walking program or the Nordic walking program. The authors assessed gait speed, stride length during 12-m, and 24-m walking trials. They also assessed postural stability before and after the training program on the basis of the UPDRS III motor score. They reported significantly longer stride length, single support time, and improvement in postural stability for participants in the NW compared to the two other groups. The authors suggested that NW was more appropriate than a flexibility program or normal walking to improve stride length, and postural stability in individuals with PD. Therefore, the increased single support time, longer stride length and faster gait speed found in our study when participants were walking with the poles suggest an improvement, which may be due to the additional external support provided by the poles.

It has been shown that specific modification in gait such as increased double support time, reduced gait speed and reduced stride length are associated with the fear of falling in older adults (Maki, 1997). It is therefore possible that the added external support when using poles improved confidence in our participants, which could have had a beneficial effect on their gait. However, besides our participants reporting feeling more confident when walking with the poles, our protocol does not allow to conclude on the effect of

NW on confidence and fear of falling, as it was not design to quantitatively assess these factors.

6.1.2 The addition of a cognitive task has different effects on spatial-temporal and regulation of trunk motion.

During longer duration walking (90 seconds), gait speed was significantly slower and gait cycle time (GCT) was longer both in NW and NP when combined to the cognitive tasks. This was to be expected as similar results were shown in the literature in both older adults (Atkinson et al., 2007; Beauchet et al., 2005; Hausdorff et al., 2008, Springer et al., 2006) and individuals with PD (O'Shea et al., 2002; Yogev et al., 2005; Galletly et al., 2005) and may be explained by the divided attention that is taking place when gait is combined with a cognitive task. However, it has been shown that the type of cognitive tasks contributed to different gait changes (Beauchet et al., 2005, Shumway-Cook et al., 1997, O'shea et al., 2002). For example, while verbal fluency depended on semantic memory, counting backwards is more depended on working memory, which is more related to executive functions. Therefore, the difficulty of a gait protocol increases when the cognitive task competes with the executive functions (Beauchet et al., 2005). In our study, the verbal fluency task was chosen as PD is already associated executive function decline (Hausdorff et al., 2006), which increases the cognitive load level to execute a well learn motor task such as gait (Wright et al., 1990, Dubois et al., 1996).

Our results suggested that the reduced gait speed might have been the direct result of attention being directed towards the cognitive task. No statistical differences were found in the spatial-temporal gait parameters between NW and NP when combined with the cognitive task. This suggests that, on one hand, walking with the poles does not significantly increase the cognitive load demand compared to normal walking. On the other hand, it could suggest that the potential improvement in postural stability does not allow compensating for the increased cognitive load demand and therefore does not improve gait spatial-temporal parameters. It is possible that a longer training program could allow participant to become more proficient with the poles, and therefore improve gait spatial-temporal characteristics. However, under its current form our protocol does not allow verifying this hypothesis.

To the contrary to spatial-temporal characteristics, NW improved trunk stability in the medial-lateral direction. Our results showed that in the longer trials, both the trunk frontal range of motion (ROM) and trunk frontal peak velocity were significantly decreased in NW compared to NP both with and without additional cognitive task. This result demonstrates that the poles improve trunk postural stability independently of the cognitive load demand. This is different from what we had hypothesised. However, this suggests that the postural benefits when walking with the poles could counteract the cognitive demand needed to manipulate the poles. It also supports the fact that a 6-week self-directed training program is appropriate to become proficient enough with the NW

technique to improve trunk stability, but not spatial-temporal characteristics such as gait speed. Moreover, we found a significantly decrease in trunk horizontal ROM when cognitive tasks assessed in NP condition, but no difference was found in NW which suggested that NW can help and regain trunk stability since the trunk became unstable when cognitive tasks assessed, but this didn't happen when participant walked with poles.

However, during shorter duration walking trials (5m), no such evidence was found for the trunk alignment. The walking pathway for the 5m trials was set so at least three steps were taken before hitting the force platforms (Robertson et al., 2013). However, when studying individuals with PD, more steps could be needed to reach a somewhat “steady-state” gait. Indeed, gait initiation has been shown to be a major deficit in PD (Rosin et al., 1997, Halliday et al., 1998, Okada et al, 2011) and the first three steps are usually quite asymmetric compared to older adults. Okada et al., (2011) reported that compared to older adults, individuals with PD have shorted step length, slower step velocity as well as excessive weight shifting during the first three steps of the gait initiation. They suggested that along medial-lateral axis, the centre of pressure (COP) in people with PD tended to deviate to the side of the swinging leg. Therefore, it could explain why NW during the 5m trials did not improve trunk motion as it did during the longer duration, as people with PD may need more steps to reach steady state gait.

6.2 Gait kinetics

The assessment of gait kinetic pattern profiles showed changes on both the weakest and strongest sides during NW. On the most affected side during mid-stance, individuals with PD generated larger peak power with their knee extensors (K2) in NW condition compared to NP. This concentric contraction with the knee extensors allows moving the centre of mass upward to assure toe clearance during swing phase of the contralateral leg (Winter 1991). Therefore, the larger K2 in NW could reduce risk of stumble and loss of balance in PD. This is of particular importance in PD since risk of falling is one of the main motor symptoms in this population (Morris et al 2000) and recurrent falls increases as the disease progresses (Cole et al., 2010). The additional support provided by the poles, as the base of support widens as well as the contribution of the arms to support the bodyweight, could allow participants to be more stable and therefore improve power generation on their weaker leg. Furthermore, this could allow a more adequate swing phase with the strongest leg, which in the end could account for the longer stride length.

No differences were found in the knee moment of force, and therefore the improvement in power generation in K2 was the result of larger knee angular velocity. As joint angular velocity is related to dynamics of muscle activation (Granata et al., 2000), this suggests that when walking with the poles, participants would not develop more

torque with the knee extensor muscles, but rather they had the ability to perform the extension of the leg faster. Therefore, as participants get used to walking with the poles and develop more normal power profiles at the knee joint, it could be useful to combined NW with a strength program to improve muscles strength particularly the knee extensors and plantarflexors, to enhance both components of joint power, i.e. moment of force and angular velocity.

On the less affected side, our results showed smaller power absorption with the knee extensors (K3) when walking with the poles compared to walking without the poles. This eccentric contraction is used to prevent the knee joint from collapsing during the push-off phase (A2) and to prepare for knee extension (Winter, 1991). This is similar to a study by Dalton et al. (2016) who reported reduced K3 in older adults when walking with poles. It is important to note that the ankle plantarflexors (A2) reaches its maximum slightly prior to the K3 peak. As previously reported by Winter (1991) and Judge et al, (1996), the power absorbed in K3 phase during normal walking is the outcome of the transfer of the energy generated by the ankle during the push-off phase (A2). Therefore, a decreased in K3 is normally associated with the reciprocate changes in A2. Therefore, the reduction in K3 suggests a smaller power generation in A2. To the contrary we found a trend ($P=0.07$) for an increase in A2 phase. Therefore, when using the poles, participants could absorb

some energy through the arms, and consequently less energy absorption would be needed with the knee extensor muscles. However, this cannot be verified, as we did not assess the energy transfer to the arms.

A trend was also found at push-off (A2) in the most affected side ($P=0.07$). PD participants showed larger ankle power generation (A2) when NW compared NP. This peak power is a very important component of forward progression during walking. Investigating gait kinetic patterns in people with PD during normal walking, previous studies reported smaller ankle power generation at A2 in individuals with PD compared to healthy controls (Sofuwa et al 2005, Morris et al., 1999). Our results did not show such a difference in A2 between our PD and control groups. However, the larger power in NW compared to NP suggests that the addition of the poles allowed participants to more efficiently used their plantarflexors during the push-off phase. The longer support time and stride length could indicate that PD participants were more stable during NW. As postural stability is a major issue in PD (Lim et al., 2007; Schaafsma et al., 2006; Atkinson et al., 2007), this enhanced postural stability conferred by the poles could allow to improve the A2 phase and a longer training program could potentially lead to significant improvement and more normal push-off in PD. Investigating the effect of a longer NW training program should therefore be considered for further studies.

One limitation of this study was the lack of pre-testing which can give us a baseline for each participant, and more information about the specific improvement when participants finished the NW training. Also, using an independent training intervention rather than a supervised training program could have been another limitation. Although the logbook can provide the participants' training records, a supervised training program could have provided participants with a more convivial environment and potentially led to larger improvement. However, we believe that the overall improvement in gait pattern after 6-week independent training program shows the beneficial effect of the intervention in PD.

CHAPTER 7: Conclusion

After a 6-week self-directed training program, walking with the Nordic poles resulted in modification in gait spatial-temporal characteristics, trunk frontal range of motion and velocity, as well as the power profiles on both the less and more affected side. The longer single support time suggests an improvement in postural stability in NW. Furthermore, when assessing the effect of the cognitive tasks, gait speed, cadence, and gait cycle time were decreased when walking without the poles, but did not further decrease when walking with the poles. The addition of the poles also improved trunk postural stability independently of the presence of a cognitive task. This suggests that NW could help regain a more normal gait pattern and improve trunk motion regulation while maintaining the cognitive load demand to a manageable level.

Regarding the effect of NW on gait kinetic pattern profiles, walking with poles improved the gait pattern on the stronger side, and also important it improved gait pattern on the weaker leg. Overall, the results presented in this thesis strongly suggest that Nordic walking could help people with PD to improve different components of gait and postural stability, without extensively increasing the cognitive load demand. Considering that gait speed is highly associated with functional mobility and independence and that a gait speed tend to decline with disease severity in individual with PD, the improvement in gait and trunk stability reported in our study suggests that NW could be an interesting and

useful rehabilitation tool to help regain a more normal gait pattern or at the least, slow the progression of the gait deficits.

Future studies should investigate the potential benefits of NW in individual with PD with more severe gait and balance deficits, e.g. individuals in stage 4 or in individuals with cognitive impairments.

TABLES

Power Mean (SD) in short walking duration

Outcome measure (W/Kg)	PD NP		PD NW		P value
	most affected side	less affected side	most affected side	less affected side	
A1	-1.02 (0.29)	-0.96 (0.36)	-1.07 (0.29)	-1.05 (0.29)	0.273
A2	3.07 (0.91)	3.19 (0.86)	3.23 (1.00)	3.18 (0.93)	0.655
K1	-1.64 (0.62)	-1.67 (0.69)	-1.59 (0.69)	-1.52 (0.50)	0.707
K2	0.87 (0.35)*	1.03 (0.33)	1.05 (0.41)	1.09 (0.39)	0.011
K3	-2.31 (1.22)	-3.12 (0.96)*	-2.35 (1.52)	-2.86 (0.86)	0.015
K4	-1.68 (1.03)	-1.61 (0.42)	-1.49 (0.70)	-1.63 (0.54)	0.118
H1	1.33 (0.56)	1.73 (0.94)	1.45 (0.64)	1.66 (0.73)	0.771
H2	-1.28 (0.57)	-1.43 (0.43)	-1.34 (0.47)	-1.50(0.48)	0.749
H3	1.81 (0.74)	2.13 (0.40)	1.79 (0.84)	2.10 (0.42)	0.195

*Significantly differ from NW at $P < 0.05$

Table 1. Lower extremity joint peak power generation/absorption

Mean peak power generation and absorption (W/kg) in the sagittal plane at the ankle, knee, and hip joints as measured during specific gait events (i.e. loading, mid-stance, push-off, terminal swing)

Moment of force Mean (SD) in short walking duration

Outcome measure (N*m/Kg)	PD NP		PD NW		P value
	most affected side	less affected side	most affected side	less affected side	
A1	-0.40 (0.12)	-0.47 (0.32)	-0.42 (0.16)	-0.51 (0.49)	0.819
A2	2.03 (0.97)	1.82 (1.02)	2.18 (0.78)	2.03 (1.09)	0.677
K1	-0.33 (0.17)	-0.30 (0.15)	-0.30 (0.14)	-0.34 (0.18)	0.778
K2	1.51 (0.89)	1.66 (0.94)	1.69 (0.81)	1.84 (0.93)	0.525
K3	-0.39 (0.36)	-0.29 (0.19)	-0.36 (0.31)	-0.32 (0.23)	0.838
K4	-0.27 (0.28)	-0.20 (0.11)	-0.15 (0.11)	-0.14 (0.08)	0.165
H1	0.58 (0.14)	0.77 (0.50)	0.45 (0.12)	0.62 (0.41)	0.156
H2	-1.40 (0.82)	-1.79 (1.10)	-1.34 (0.91)	-1.79(0.93)	0.951
H3	1.27 (0.61)	1.58 (0.77)	1.38 (0.67)	1.66 (0.81)	0.078

Table 2. Lower extremity joint peak moment of force

Mean peak moment of force (N*m/Kg) in the sagittal plane at the ankle, knee, and hip joints as measured during specific gait events (i.e. loading, mid-stance, push-off, terminal swing)

Table 3. Spatial-temporal results

Spatial-temporal (SD) in long walking duration

Outcome measure	Without cognitive task		With cognitive task		P value
	NP	NW	NP	NW	
Stride length (m)	1.46 (0.11)*^	1.49 (0.12)^	1.43 (0.13)*	1.46 (0.14)	0.041
Gait velocity (m/s)	1.42 (0.12)^	1.40 (0.11)^	1.31 (0.11)	1.31 (0.13)	0.008
Cadence (step/min)	117.08 (8.18)^	113.21 (8.22)^	110.89 (9.6)	108.41 (11.9)	0.054
Gait cycle time (s)	1.03 (0.07)	1.07 (0.08)	1.09 (0.10)	1.12 (0.13)	0.070
Double support time (%)	21.31 (3.00)	21.77 (3.50)	22.62 (3.43)	22.44 (3.13)	0.017

*Significantly differ with NW at $P < 0.05$ ^Significantly differ with “with cognitive task” at $P < 0.05$

Mean spatial-temporal gait characteristics with poles (NW) and without poles (NP).

These are the averages and standard deviation of the group gathered from APDM motion capture systems, representing gait as recorded over 90 seconds.

Table 4. Results for trunk motion regulation

Regulation of Trunk motion (SD) in long walking duration

Outcome measure	Without cognitive task		With cognitive task		P value
	NP	NW	NP	NW	
Trunk Frontal ROM (Deg)	8.4 (2.43)*^	8.23 (3.31)	9.85 (2.65)*	8.11 (3.06)	0.004
Trunk Sagittal ROM (Deg)	4.57 (1.17)	4.62 (1.59)	4.84 (1.51)	4.83 (1.42)	0.837
Trunk Horizontal ROM (Deg)	4.58 (1.27)^	5.20 (1.38)	5.39 (1.32)	5.55 (1.47)	0.049
Trunk Frontal velocity (Deg/s)	36.11 (9.02)*	34.38 (11.04)	39.09 (8.87)*	33.23 (9.80)	0.000
Trunk Sagittal velocity (Deg/s)	31.45 (9.02)	32.85 (11.13)	29.2 (9.48)	31.48 (9.96)	0.844
Trunk Horizontal velocity (Deg/s)	21.59 (6.91)	23.03 (4.80)	21.11 (5.05)	22.39 (3.97)	0.892

*Significantly differ with NW at $P < 0.05$ ^Significantly differ with “with cognitive task” at $P < 0.05$

Mean regulation of trunk motion comparing with poles (NW) and without poles (NP).

These are the averages and standard deviation of the group gathered from APDM motion capture systems, representing gait as recorded over 90 seconds.

Table 5. Spatial-temporal results

Spatial temporal Mean (SD) in short walking duration

Outcome measure	PD NP	PD NW	P value
Stride Length (m)	1.34 (0.16)*	1.42 (0.16)	0.001
Gait velocity (m/s)	1.27 (0.19)	1.31 (0.19)	0.16
Cadence (step/min)	112.25 (10.57)*	107.62 (10.01)	0.004
Double Support Time (s)	0.29 (0.07)	0.30 (0.07)	0.64
Single Support Time (s)	0.40 (0.04)*	0.43 (0.05)	0.003

*Significantly differ with NW at $P < 0.05$

Mean spatial-temporal gait characteristics comparing with poles (NW) and without poles (NP). These are the averages and standard deviation of the group gathered from Vicon motion capture systems, representing gait as recorded over short duration (5m).

Table 6. Results for joint range of motion

Joint Range of Motion (SD) in short walking duration

Outcome measure	NP		NW		P value
	Most affected side	Less affected side	Most affected side	Less affected side	
Ankle (Degree)	27.38 (5.44)	30.51 (8.49)	27.57 (4.38)	31.60 (7.29)	0.87
Knee (Degree)	59.40 (7.37)	61.83 (7.03)	59.59 (7.73)	63.19 (5.40)	0.83
Hip (Degree)	44.23 (4.88)	45.77 (2.93)	47.26 (4.51)	48.23 (4.45)	0.08

Mean Joint range of motion comparing with poles (NW) and without poles (NP). These are the averages of the group gathered from Vicon motion capture systems, representing gait as recorded over short duration (5m).

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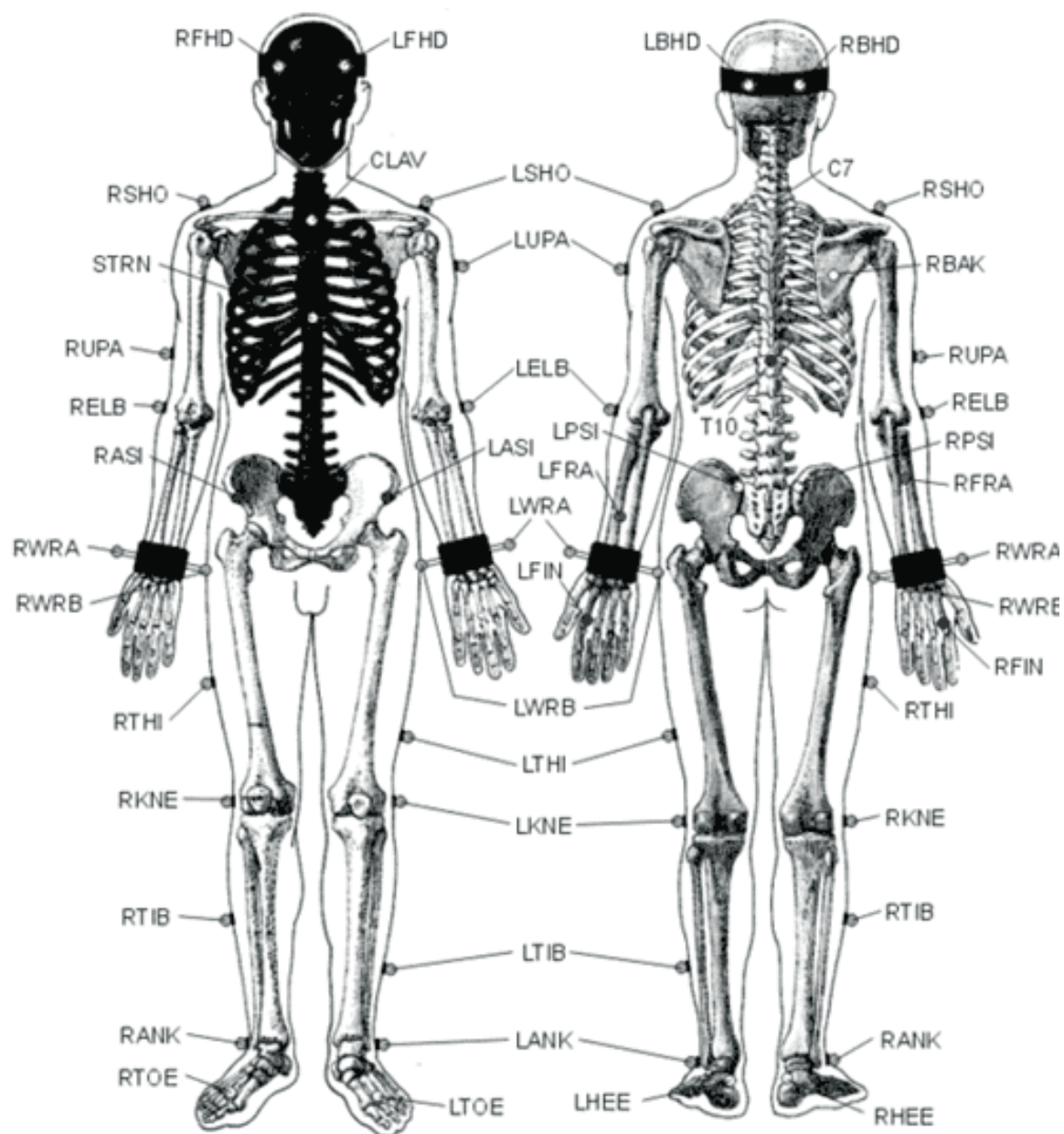
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FIGURES:

Plug-in Gait Marker Set



APPENDIX A:

Montreal Cognitive Assessment (MoCA)

MONTREAL COGNITIVE ASSESSMENT (MOCA) Version 7.1 Original Version		NAME : Education : Sex : Date of birth : DATE :																			
VISUOSPATIAL / EXECUTIVE		POINTS																			
		Copy cube Draw CLOCK (Ten past eleven) (3 points)	[] /5																		
NAMING		POINTS																			
			[] /3																		
MEMORY		POINTS																			
Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful. Do a recall after 5 minutes.		<table border="1" style="width: 100%; text-align: center;"> <tr> <td></td> <td>FACE</td> <td>VELVET</td> <td>CHURCH</td> <td>DAISY</td> <td>RED</td> </tr> <tr> <td>1st trial</td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>2nd trial</td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> </table>		FACE	VELVET	CHURCH	DAISY	RED	1st trial						2nd trial						No points
	FACE	VELVET	CHURCH	DAISY	RED																
1st trial																					
2nd trial																					
ATTENTION		POINTS																			
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																			
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																			
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																			
LANGUAGE		POINTS																			
Repeat : I only know that John is the one to help today. []		[] /2																			
The cat always hid under the couch when dogs were in the room. []		[] /1																			
Fluency / Name maximum number of words in one minute that begin with the letter F		[] ____ (N ≥ 11 words)																			
ABSTRACTION		POINTS																			
Similarity between e.g. banana - orange = fruit		[] train - bicycle [] watch - ruler																			
DELAYED RECALL		POINTS																			
Has to recall words	FACE	VELVET	CHURCH	DAISY	RED	Points for UNCUEDE recall only	[] /5														
WITH NO CUE	[]	[]	[]	[]	[]																
Category cue																					
Optional		POINTS																			
Multiple choice cue																					
ORIENTATION		POINTS																			
[] Date [] Month [] Year [] Day [] Place [] City		[] /6																			
© Z.Nasreddine MD www.mocatest.org Normal ≥ 26 / 30		TOTAL [] /30 Add 1 point if ≤ 12 yr edu																			

Montreal Cognitive Assessment (MoCA)

Administration and Scoring Instructions

Time to administer the MoCA is approximately 10 minutes. The total possible score is 30 points; a score of 26 or above is considered normal.

1. Alternating Trail Making:

Administration: The examiner instructs the subject: *"Please draw a line, going from a number to a letter in ascending order. Begin here [point to (1)] and draw a line from 1 then to A then to 2 and so on. End here [point to (E)]."*

Scoring: Allocate one point if the subject successfully draws the following pattern: 1 –A- 2- B- 3- C- 4- D- 5- E, without drawing any lines that cross. Any error that is not immediately self-corrected earns a score of 0.

2. Visuoconstructional Skills (Cube):

Administration: The examiner gives the following instructions, pointing to the cube: *"Copy this drawing as accurately as you can, in the space below".*

Scoring: One point is allocated for a correctly executed drawing.

- Drawing must be three-dimensional
- All lines are drawn
- No line is added
- Lines are relatively parallel and their length is similar (rectangular prisms are accepted)

A point is not assigned if any of the above-criteria are not met.

3. Visuoconstructional Skills (Clock):

Administration: Indicate the right third of the space and give the following instructions: *"Draw a **clock**. Put in all the numbers and set the time to 10 after 11".*

Scoring: One point is allocated for each of the following three criteria:

- Contour (1 pt.): the clock face must be a circle with only minor distortion acceptable (e.g., slight imperfection on closing the circle);
- Numbers (1 pt.): all clock numbers must be present with no additional numbers; numbers must be in the correct order and placed in the approximate quadrants on the clock face; Roman numerals are acceptable; numbers can be placed outside the circle contour;

- Hands (1 pt.): there must be two hands jointly indicating the correct time; the hour hand must be clearly shorter than the minute hand; hands must be centred within the clock face with their junction close to the clock centre.

A point is not assigned for a given element if any of the above-criteria are not met.

4. Naming:

Administration: Beginning on the left, point to each figure and say: *"Tell me the name of this animal"*.

Scoring: One point each is given for the following responses: (1) camel or dromedary, (2) lion, (3) rhinoceros or rhino.

5. Memory:

Administration: The examiner reads a list of 5 words at a rate of one per second, giving the following instructions: *"This is a memory test. I am going to read a list of words that you will have to remember now and later on. Listen carefully. When I am through, tell me as many words as you can remember. It doesn't matter in what order you say them"*. Mark a check in the allocated space for each word the subject produces on this first trial. When the subject indicates that (s)he has finished (has recalled all words), or can recall no more words, read the list a second time with the following instructions: *"I am going to read the same list for a second time. Try to remember and tell me as many words as you can, including words you said the first time."* Put a check in the allocated space for each word the subject recalls after the second trial.

At the end of the second trial, inform the subject that (s)he will be asked to recall these words again by saying, *"I will ask you to recall those words again at the end of the test."*

Scoring: No points are given for Trials One and Two.

6. Attention:

Forward Digit Span: Administration: Give the following instruction: *"I am going to say some numbers and when I am through, repeat them to me exactly as I said them"*. Read the five number sequence at a rate of one digit per second.

Backward Digit Span: Administration: Give the following instruction: *"Now I am going to say some more numbers, but when I am through you must repeat them to me in the backwards order."* Read the three number sequence at a rate of one digit per second.

Scoring: Allocate one point for each sequence correctly repeated, (N.B.: the correct response for the backwards trial is 2-4-7).

Vigilance: Administration: The examiner reads the list of letters at a rate of one per second, after giving the following instruction: *"I am going to read a sequence of letters. Every time I say the letter A, tap your hand once. If I say a different letter, do not tap your hand"*.

Scoring: Give one point if there is zero to one errors (an error is a tap on a wrong letter or a failure to tap on letter A).

Serial 7s: Administration: The examiner gives the following instruction: *"Now, I will ask you to count by subtracting seven from 100, and then, keep subtracting seven from your answer until I tell you to stop."* Give this instruction twice if necessary.

Scoring: This item is scored out of 3 points. Give no (0) points for no correct subtractions, 1 point for one correct subtraction, 2 points for two-to-three correct subtractions, and 3 points if the participant successfully makes four or five correct subtractions. Count each correct subtraction of 7 beginning at 100. Each subtraction is evaluated independently; that is, if the participant responds with an incorrect number but continues to correctly subtract 7 from it, give a point for each correct subtraction. For example, a participant may respond "92 – 85 – 78 – 71 – 64" where the "92" is incorrect, but all subsequent numbers are subtracted correctly. This is one error and the item would be given a score of 3.

7. Sentence repetition:

Administration: The examiner gives the following instructions: *"I am going to read you a sentence. Repeat it after me, exactly as I say it [pause]: **I only know that John is the one to help today.**"* Following the response, say: *"Now I am going to read you another sentence. Repeat it after me, exactly as I say it [pause]: **The cat always hid under the couch when dogs were in the room.**"*

Scoring: Allocate 1 point for each sentence correctly repeated. Repetition must be exact. Be alert for errors that are omissions (e.g., omitting "only", "always") and substitutions/additions (e.g., "John is the one who helped today;" substituting "hides" for "hid", altering plurals, etc.).

8. Verbal fluency:

Administration: The examiner gives the following instruction: *"Tell me as many words as you can think of that begin with a certain letter of the alphabet that I will tell you in a moment. You can say any kind of word you want, except for proper nouns (like Bob or Boston), numbers, or words that begin with the same sound but have a different*

suffix, for example, love, lover, loving. I will tell you to stop after one minute. Are you ready? [Pause] Now, tell me as many words as you can think of that begin with the letter F. [time for 60 sec]. Stop."

Scoring: Allocate one point if the subject generates 11 words or more in 60 sec. Record the subject's response in the bottom or side margins.

9. Abstraction:

Administration: The examiner asks the subject to explain what each pair of words has in common, starting with the example: *"Tell me how an orange and a banana are alike"*. If the subject answers in a concrete manner, then say only one additional time: *"Tell me another way in which those items are alike"*. If the subject does not give the appropriate response (fruit), say, *"Yes, and they are also both fruit."* Do not give any additional instructions or clarification.

After the practice trial, say: *"Now, tell me how a train and a bicycle are alike"*. Following the response, administer the second trial, saying: *"Now tell me how a ruler and a watch are alike"*. Do not give any additional instructions or prompts.

Scoring: Only the last two item pairs are scored. Give 1 point to each item pair correctly answered. The following responses are acceptable:

Train-bicycle = means of transportation, means of travelling, you take trips in both;

Ruler-watch = measuring instruments, used to measure.

The following responses are **not** acceptable: Train-bicycle = they have wheels; Ruler-watch = they have numbers.

10. Delayed recall:

Administration: The examiner gives the following instruction: *"I read some words to you earlier, which I asked you to remember. Tell me as many of those words as you can remember."* Make a check mark for each of the words correctly recalled spontaneously without any cues, in the allocated space.

Scoring: Allocate 1 point for each word recalled freely without any cues.

Optional: Following the delayed free recall trial, prompt the subject with the semantic category cue provided below for any word not recalled. Make a check mark (3) in the allocated space if the subject remembered the word with the help of a category or multiple-choice cue. Prompt all non-recalled words in this manner. If the subject does not recall the word after the category cue, give him/her a multiple

choice trial, using the following example instruction, *“Which of the following words do you think it was, NOSE, FACE, or HAND?”*

Use the following category and/or multiple-choice cues for each word, when appropriate:

FACE: category cue: part of the body multiple choice: nose, face, hand

VELVET: category cue: type of fabric multiple choice: denim, cotton, velvet

CHURCH: category cue: type of building multiple choice: church, school, hospital

DAISY: category cue: type of flower multiple choice: rose, daisy, tulip

RED: category cue: a colour multiple choice: red, blue, green

Scoring: No points are allocated for words recalled with a cue. A cue is used for clinical information purposes only and can give the test interpreter additional information about the type of memory disorder. For memory deficits due to retrieval failures, performance can be improved with a cue. For memory deficits due to encoding failures, performance does not improve with a cue.

11. Orientation:

Administration: The examiner gives the following instructions: *“Tell me the date today”*. If the subject does not give a complete answer, then prompt accordingly by saying: *“Tell me the [year, month, exact date, and day of the week].”* Then say: *“Now, tell me the name of this place, and which city it is in.”*

Scoring: Give one point for each item correctly answered. The subject must tell the exact date and the exact place (name of hospital, clinic, office). No points are allocated if subject makes an error of one day for the day and date.

TOTAL SCORE: Sum all subscores listed on the right-hand side. Add one point for an individual who has 12 years or fewer of formal education, for a possible maximum of 30 points. A final total score of 26 and above is considered normal.

APPENDIX B:

Unified Parkinson's disease rating scale (UPDRS III)

The UPDRS motor subscale (III) is the most commonly used scale in the clinical study of Parkinson's disease.

III. Motor Examination

18. Speech

- 0 = Normal.
- 1 = Slight loss of expression, diction and/or volume.
- 2 = Monotone, slurred but understandable; moderately impaired.
- 3 = Marked impairment, difficult to understand.
- 4 = Unintelligible.

19. Facial Expression

- 0 = Normal.
- 1 = Minimal hypomimia, could be normal "Poker Face."
- 2 = Slight but definitely abnormal diminution of facial expression
- 3 = Moderate hypomimia; lips parted some of the time.
- 4 = Masked or fixed facies with severe or complete loss of facial expression; lips parted $\frac{1}{4}$ inch or more.

20. Tremor at Rest (head, upper and lower extremities)

- 0 = Absent.
- 1 = Slight and infrequently present.
- 2 = Mild in amplitude and persistent. Or moderate in amplitude, but only intermittently present.
- 3 = Moderate in amplitude and present most of the time.
- 4 = Marked in amplitude and present most of the time.

21. Action or Postural Tremor of Hands

- 0 = Absent.
- 1 = Slight; present with action.
- 2 = Moderate in amplitude, present with action.
- 3 = Moderate in amplitude with posture holding as well as action.
- 4 = Marked in amplitude; interferes with feeding.

22. Rigidity (Judged on passive movement of major joints with patient relaxed in sitting position. Cogwheeling to be ignored.)

- 0 = Absent.
- 1 = Slight or detectable only when activated by mirror or other movements.
- 2 = Mild to moderate.
- 3 = Marked, but full range of motion easily achieved.
- 4 = Severe, range of motion achieved with difficulty.

23. Finger Taps (Patient taps thumb with index finger in rapid succession.)

- 0 = Normal.
- 1 = Mild slowing and/or reduction in amplitude.
- 2 = Moderately impaired. Definite and early fatiguing. May have occasional arrests in movement.
- 3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement.
- 4 = Can barely perform the task.

24. Hand Movements (Patient opens and closes hands in rapid succession.)

- 0 = Normal.
- 1 = Mild slowing and/or reduction in amplitude.
- 2 = Moderately impaired. Definite and early fatiguing. May have occasional arrests in movement.
- 3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement.
- 4 = Can barely perform the task.

25. Rapid Alternating Movements of Hands

- (Pronation-supination movements of hands, vertically and horizontally, with as large an amplitude as possible, both hands simultaneously.)
- 0 = Normal.
 - 1 = Mild slowing and/or reduction in amplitude.
 - 2 = Moderately impaired. Definite and early fatiguing. May have occasional arrests in movement.
 - 3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement.
 - 4 = Can barely perform the task.

26. Leg Agility (Patient taps heel on the ground in rapid succession picking up entire leg. Amplitude should be at least 3 inches.)

0 = Normal.

1 = Mild slowing and/or reduction in amplitude.

2 = Moderately impaired. Definite and early fatiguing. May have occasional arrests in movement.

3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement.

4 = Can barely perform the task.

27. Arising from Chair (Patient attempts to rise from a straightbacked chair, with arms folded across chest.)

0 = Normal.

1 = Slow; or may need more than one attempt.

2 = Pushes self up from arms of seat.

3 = Tends to fall back and may have to try more than one time, but can get up without help.

4 = Unable to arise without help.

28. Posture

0 = Normal erect.

1 = Not quite erect, slightly stooped posture; could be normal for older person.

2 = Moderately stooped posture, definitely abnormal; can be slightly leaning to one side.

3 = Severely stooped posture with kyphosis; can be moderately leaning to one side.

4 = Marked flexion with extreme abnormality of posture.

29. Gait

0 = Normal.

1 = Walks slowly, may shuffle with short steps, but no festination (hastening steps) or propulsion.

2 = Walks with difficulty, but requires little or no assistance; may have some festination, short steps, or propulsion.

3 = Severe disturbance of gait, requiring assistance.

4 = Cannot walk at all, even with assistance.

30. Postural Stability (Response to sudden, strong posterior displacement produced by pull on shoulders while patient erect with eyes open and feet slightly apart. Patient is prepared.)

0 = Normal.

1 = Retropulsion, but recovers unaided.

2 = Absence of postural response; would fall if not caught by examiner.

3 = Very unstable, tends to lose balance spontaneously.

4 = Unable to stand without assistance.

31. Body Bradykinesia and Hypokinesia (Combining slowness, hesitancy, decreased arm swing, small amplitude, and poverty of movement in general.)

0 = None.

1 = Minimal slowness, giving movement a deliberate character; could be normal for some persons. Possibly reduced amplitude.

2 = Mild degree of slowness and poverty of movement which is definitely abnormal. Alternatively, some reduced amplitude.

3 = Moderate slowness, poverty or small amplitude of movement.

4 = Marked slowness, poverty or small amplitude of movement.

APPENDIX C:

Physical Activity Readiness Questionnaire (PAR-Q)

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
☐	☐	1. Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?
☐	☐	2. Do you feel pain in your chest when you do physical activity?
☐	☐	3. In the past month, have you had chest pain when you were not doing physical activity?
☐	☐	4. Do you lose your balance because of dizziness or do you ever lose consciousness?
☐	☐	5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?
☐	☐	6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
☐	☐	7. Do you know of any other reason why you should not do physical activity?

If
you
answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active — begin slowly and build up gradually. This is the safest and easiest way to go.

- take part in a fitness appraisal — this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever — wait until you feel better; or
- if you are or may be pregnant — talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME _____

SIGNATURE _____

DATE _____

SIGNATURE OF PARENT _____

WITNESS _____

or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.



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APPENDIX D:

Evaluation of socio-cultural level

Standardized Interview:

Right: Left:

Side affected:

Date of birth:

Height:

Dx:

Mother tongue / Languages / Language favorite conversation:

What is your marital status?

1) Married?

2) In a common?

3) Widow?

4) Separated?

5) Divorced?

6) Single (never married)?

- What is (was) your occupation? retired / technologist

- Have you held other professional activities during your career

(Record verbatim answers the subject)? _____

- How old do you have continued the studies? (Or) until what age did you go (s) at school?

- What is the highest diploma you have obtained or what is your highest qualification?

- Do you take an anti-parkinsonian medication? Dose (mg / day)

- Have you had injuries / surgeries in the lower limbs?

- Do you have problems / neurological conditions?

Medical follow:

Physical activity level for the elderly and physical activity barriers

How physically active are you?

(Check one answer on each line)

Rapa 1

Does this accurately
describe you?

1	I rarely or never do any physical activity	Yes ☐ No ☐
2	I do some light or moderate physical activities, but not every week.	Yes ☐ No ☐
3	I do some light physical activity every week.	Yes ☐ No ☐
4	I do moderate physical activities every week, but less than 30 minutes a day or 5 days a week.	Yes ☐ No ☐
5	I do vigorous physical activities every week, but less than 20 minutes a day or 3 days a week.	Yes ☐ No ☐
6	I do 30 minutes or more a day of moderate physical activities, 5 or more days a week.	Yes ☐ No ☐
7	I do 20 minutes or more a day of vigorous physical activities, 3 or more days a week.	Yes ☐ No ☐

Rapa 2

1	I do activities to increase muscle strength , such as lifting weights or calisthenics, once a week or more.	Yes ☐ No ☐
2	I do activities to improve flexibility , such as stretching or yoga, once a week or more.	Yes ☐ No ☐

What prevents you from participating in physical activities?

- | | |
|---|---|
| i. Cost | viii. Don't want to go alone |
| ii. Transportation problems | ix. Personal or family responsibilities |
| iii. Activities not available in the area | x. Language related reasons |
| iv. Location not physically accessible | xi. Too busy |
| v. Location is too far | xii. Afraid of concerns about safety |
| vi. Health condition limitation | xiii. Other (specify) |
| vii. Time of activities not suitable | |

APPENDIX E:

Category task: Participants need to say different names during testing.
Instructor will record their answer and the time.

Subject Number:

	Name a color	Name an animal	Name a number	Name a season
1				
2				
3				
4				

APPENDIX F:

Postural stability and Falls Questionnaire (Adapted from Ashburn et al. 2008)

Definition of a fall: ‘An event that results in a person coming to rest unintentionally on the ground or other lower level, not as the result of a major intrinsic event (individual) or overwhelming hazard’.

1. Please indicate how many times you fell in the last 3 months.

In the last year. _____

2. How often do you fall:

0 Never

1 Very rarely - about once a month

2 Rarely - about once a week

3 Often - about once a day

4 Always - whenever walking

3. Please answer the following questions :

Where were you when you fell?

What were you trying to do at the time?

What do you think caused you to fall?

How did you land?

What injuries did you sustain? How did you get up again?

What health care did you receive?

Are you worried or concerned that in the future you might fall?

As a result of this concern, have you stopped doing some things you used to do or liked to do?

Nordic Walking Guidelines & Physical Activity Log



APPENDIX G:

Anthropometric Data Collection

SUBJECT ID #: _____

General

Body mass (kg)		Height (mm)		Inter-ASIS Distance (mm)	
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Measurements (mm)

Left		Right	
Leg Length		Leg Length	
Knee width		Knee width	
Ankle width		Ankle width	
Shoulder offset		Shoulder offset	
Elbow width		Elbow width	
Wrist width		Wrist width	
Hand thickness		Hand thickness	

SUBJECT ID #: _____

General

Body mass (kg)		Height (mm)		Inter-ASIS Distance (mm)	
------------------------------------	--	-----------------------------	--	---	--

Measurements (mm)

Left		Right	
Leg Length		Leg Length	
Knee width		Knee width	
Ankle width		Ankle width	
Shoulder offset		Shoulder offset	
Elbow width		Elbow width	
Wrist width		Wrist width	
Hand thickness		Hand thickness	