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Antonio Henrique Leal do Nascimento

PHYSIOMECHANICAL RESPONSES OF GAIT WITH POLES IN PEOPLE WITH PARKINSON'S DISEASE

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Orientador: Prof. Dr. Leonardo Alexandre Peyré Tartaruga
Coorientador: Prof. Dr. Rafael Reimann Baptista

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BANCA EXAMINADORA

Prof. Drª. Aline Nogueira Haas
Universidade Federal do Rio Grande do Sul – UFRGS

Prof. Dr ª. Elren Passos Monteiro
Universidade Federal do Pará – UFPA

Prof. Dr. Luca Paolo Ardigò
Università degli Studi di Verona – UNIVR, Itália

Prof. Dr ª. Natalia Andrea Gomeñuka
Universidad Católica de las Misiones – UCAMI, Argentina

Orientador – Prof. Dr. Leonardo Alexandre Peyré Tartaruga
Universidade Federal do Rio Grande do Sul - UFRGS

Dedicada aos meus pais e minha irmã

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RESUMO

Introdução: A doença de Parkinson (DP) impacta na locomoção diminuindo a velocidade da marcha, o comprimento e frequência de passo, ativação muscular, e aumenta a variabilidade e o gasto energético da marcha. Estes fatores estão associados a um aumento do risco de quedas e a redução das atividades de vida diária e da qualidade de vida. As intervenções de caminhada Nórdica (CN) são conhecidas por melhorar os parâmetros da marcha e reduzir os sintomas motores a longo prazo. No entanto, ainda é desconhecido o efeito agudo dos bastões sobre as flutuações das energias mecânicas, parâmetros cinéticos e espaço-temporais da marcha de pessoas com DP. **Objetivo:** O nosso objetivo foi comparar os parâmetros mecânicos, mecanismo pendular, cinéticos e espaço-temporais da marcha em diferentes velocidades com e sem bastões de CN em pessoas com DP e controles saudáveis. **Métodos**: Os estudos que compuseram a dissertação incluíram 11 pessoas (idade 65,6 ± 7,0 anos) com DP idiopática, estagiamento entre 1 e 1,5 na escala de Hoehn e Yahr, e nove controles saudáveis (idade 70,0 ± 5,6 anos). Todas as pessoas eram praticantes experientes de CN. Os dados foram coletados em três velocidades de caminhada, 1,8 $km.h^{-1}$, 4,7 $km.h^{-1}$, velocidade máxima de caminhada, e uma velocidade de corrida autosselecionada através de oito plataformas de força 3D implementadas a uma passarela. O *Generalized Linear Model* foi utilizado para identificar efeitos principais de grupo (grupo Parkinson × controle), modalidade (CL × CN) e interações (grupo × modalidade). O *post hoc* de Bonferroni foi utilizado para encontrar diferenças estatísticas em caso de interações significativas. **Resultados**: Encontramos um maior *recovery* pendular ($p<0,05$) no grupo de Parkinson durante a CN em relação à caminhada livre (CL), enquanto que o trabalho mecânico externo permaneceu semelhante ($p>0,05$). As pessoas com DP mostraram um significativo aumento na flutuação das energias verticais e *forward* utilizando bastões em comparação a controles saudáveis. Além disso, pessoas com DP demostraram um aumento da frequência de passo e uma redução do comprimento de passo em comparação com os controles durante CN e CL. O trabalho mecânico total foi aumentado devido ao trabalho mecânico interno durante a CN de forma semelhante no grupo Parkinson e o controles saudáveis. Nossos resultados justificam parcialmente a menor economia durante a CL na DP devido ao maior trabalho total e a redução do *recovery* em velocidade habitualmente utilizada. Durante a máxima velocidade caminhada, nós encontramos aumento dos componentes verticais (apoio terminal) e anteroposteriores (*braking* e *propulsive*) das forças de reação do solo (FRS) ($p<0,005$) no grupo Parkinson durante o CN, em comparação com a CL. Durante a corrida nórdica, sujeitos com DP diminuíram os componentes verticais das FRS ($p<0,005$) e os componentes anteroposteriores permaneceram inalterados ($p>0,005$) em comparação com os controles saudáveis. A frequência de passo foi reduzida ($p>0,005$) em DP de forma semelhante aos controles durante CN e corrida Nórdica. **Conclusão**: concluímos que caminhar e correr com bastões são atividades funcionais e seguras. Portanto, pode ser uma estratégia útil de reabilitação devido ao seu potencial para aumentar a mobilidade funcional e recuperação de energia mecânica, bem como alterar o trabalho mecânico externo e os componentes cinéticos, resultando em determinantes mecânicos importantes do custo energético da locomoção em pessoas com DP.

Palavras-chave: Parkinsonianos, caminhada nórdica, corrida nórdica, fisiomecânica.

ABSTRACT

Background: Parkinson's disease (PD) affects the locomotion decreasing gait speed, step length and frequency, and muscle activation, and increasing the gait variability and energy expenditure. These factors are associated with an increased risk of falls and reduced activities of daily living and quality of life. The Nordic walking (NW) interventions are known to improve gait parameters and reduce motor symptoms in the long term. However, the acute effect of poles on the mechanical energies' fluctuations, kinetic and spatiotemporal parameters in people with PD is still unknown. **Objective:** We aimed to compare mechanical parameters, pendulum-like mechanism, kinetic, and spatiotemporal variables of gait at different speeds gait with and without NW poles in people with PD and healthy controls. **Methods**: The dissertation studies included 11 people (aged 65.6±7.0 years) with idiopathic PD, scoring between 1 and 1.5 on the Hoehn and Yahr scale (H&Y), and nine healthy controls (aged 70.0±5.6 years). All the people were experienced Nordic walkers. Data was collected with people at three walking speed, 1.8 km.h^{-1}, 4.7 km.h^{-1}, fast-walking speed and a self-select running speed on eight 3D force platforms on a walkway. Generalized Linear Model was used to identify the main effects group (control × Parkinson's group), modality (FW × NW), and group × modality interactions, and Bonferroni post hoc was used to find statistical differences. **Results:** We found greater pendulum-like energy recovery ($p<0.05$) in the Parkinson's group during NW than in free walking (FW), while external mechanical work remained similar ($p>0.05$). People with PD showed a major increase in vertical and forward energy fluctuations using poles than in healthy controls. In addition, the PD showed increased step frequency and reduced step length compared to controls in NW and FW conditions. Our findings partly justify the lower walking economy in PD during FW due to higher total work and reduced pendulum-like mechanism at commonly used speeds. NW increases the total work due to internal work similarly in Parkinson's group and healthy control. During fast-walking speed we found greater vertical (terminal stance) and anteroposterior (braking and propulsive) components of the ground reaction force (GRF) ($p<0.005$) in the Parkinson group during NW in comparison FW. During Nordic running (NR), people with PD decreased the vertical components of the GRF ($p<0.005$) and remained unchanged anteroposterior components ($p>0.005$) compared to the healthy controls. The NW and NR reduced step frequency ($p>0.005$) similarly in both groups. These finds suggest NW and NR modify gait patterns and lead to compensatory adjustments to reduce motor symptoms of PD. **Conclusion:** we concluded walking and running with poles are functional and safe activities. Therefore, it can be a compelling strategy for rehabilitation because of its potential to improve functional mobility, increase pendulum-like energy recovery, external mechanical work, kinetic components and impacts the energy cost of PD locomotion.

Keywords: Parkinsonians, Nordic walking, Nordic running, physiomechanics.

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LIST OF ABBREVIATIONS

%	Percentage
m	Minutes
($^{\#}$)	Remains similar
3D	Three-dimensional
6MWT	Six-minute walking test
↑	Greater for Parkinson group
↓	Lower for Parkinson group
WS	Walking speed
SF	Step frequency
SL	Step length
SW	Step width
DST	Double stance time
cm	Centimeter
ST	Swing time
CT	Contact time
s	Seconds
STV	Swing time variability
ESEFID	School of Physical Education, Physiotherapy and Dance
PUC	Pontifical Catholic University of Rio Grande do Sul
LAPAFI	Physical Activity Research and Evaluation Laboratory
FW	Free walking
GLZM	Generalized Linear Model
H&Y	Hoehn and Yahr scale
HC	Healthy control
kg	Kilograms
LAPEX	Exercise Research Laboratory
W_{tot}	Total mechanical work
m	Meters

$m.s^{-1}$	Meter per second
W_{ext}	External mechanical work
mm	Millimeter
W_{int}	Internal mechanical work
W_v	Vertical mechanical work
NW	Nordic walking
W_f	Forward mechanical work
ON	Medication effect period
PD	Parkinson’s disease
GRF	Ground reaction forces
R	Recovery
J	Joule
SPSS	Statistical Package for Social Sciences
SSWS	Self-selected walking speed
kg	Kilogram
UFRGS	Universidade Federal do Rio Grande do Sul
UPDRS	Unified Parkinson's disease Rating Scale
±	plus-minus sign
α	Alfa
BCoM	Body center of mass
$>$	Major
$<$	Minor
$km.h^{-1}$	Kilometers per hour
v	Version
T	Period
F_v	Vertical force
BW	Body weight
m	Mass
a	Acceleration
F_f	Forward force
a_v	Vertical acceleration

a_f	Forward acceleration
KE_f	Forward kinetic energy
KEv	Vertical kinetic energy
V_f	Forward velocity
Vv	Vertical velocity
PE	gravitational potential energy
g	Gravitational acceleration
h	Height
Etot	Total mechanical energy
T Up	Tau fraction upward displacement
T Down	Tau fraction downward displacement
p	p value
†	within-effect (with versus without poles) in Parkinson group
‡	within-effect (with versus without poles) in healthy control group
§	between-effect (PD versus HC) in FW and NW conditions

SUMMARY

CHAPTER 1

GENERAL INTRODUCTION

This chapter consists of four sections: general presentation, problem and importance of research, aims, and finally, a literature review.

1.1 General presentation

1.1.1 Contextualization and delimitation of the study

The LOCOMOTION Research Group - Mechanics and Energetics of Terrestrial Locomotion is coordinated by Leonardo Alexandre Peyré Tartaruga from Exercise Research Laboratory (LAPEX) of the School of Physical Education, Physiotherapy and Dance (ESEFID) at the Federal University of Rio Grande do Sul (UFRGS). It is dedicated to investigating the mechanical and energetic determinants of walking, running, and jumping applied to diverse populations.

The present dissertation aimed to answer the following question: what are the biomechanical responses of walking and running with poles in people with Parkinson's disease (PD)? For this, we have made a partnership with the Exercise Physiology and biomechanics research group (FISIOMEC) coordinated by Professor Rafael Reimann Baptista from the Laboratory of Research and Evaluation in Physical Activity (LAPAFI) at the Pontifical Catholic University of Rio Grande do Sul (PUCRS). The partnership main was to combine the expertise of gait analysis based on the ground reaction forces (GRF) from FISIOMEC with expertise in gait mechanics and energetics analysis in people with PD from the LOCOMOTION.

My first contact about gait studies of people with PD at the Brazilian Congress of biomechanics in Manaus, Brazil, in 2019. Since then, I have dedicated myself to studying the topic and started my master's degree with the research group LOCOMOTION at UFRGS. In my master's, I had the opportunity to work in Nordic walking (NW) projects for the community, participate in conferences, meet several researchers, and learn a lot from all these experiences. Besides my advisors, Leonardo Alexandre Peyré Tartaruga and Rafael Reimann Baptista, many people have contributed to the achievement of this dissertation such as: Daniela Santo Abreu (Scientific Initiation), Daniela Luft (Scientific

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1.1.2 Structure of dissertation

The dissertation is divided into five chapters. The first chapter presents a general introduction and shows the objectives of the following chapters. The second chapter provides an observational study on mechanical work and spatiotemporal parameters response of NW people with PD compared to healthy control. The third chapter provides an observational study on the GRF responses during fast walking and running with poles of people with PD compared to healthy control. The fourth chapter analyzed and summarized the results from the two studies. Finally, the firth summarizes the scientific work produced during the master's degree.

1.2 Problem statement

Neurological diseases represent the most significant cause of disability and the second largest cause of death worldwide. The PD is the second most common neurodegenerative disease (FEIGIN et al., 2019). The incidence of PD has increased from five to over 35 new cases per 100,000 people annually, doubling from five to ten cases from the sixth to the ninth decade of life. Prevalence has increased from less than 1% in men and women aged 45 to 54 years to 4% in men and 2% in women aged 85 and older, associated with increased deaths after the first decade of diagnosis. The following two decades are estimated to double the prevalence of cases (SIMON; TANNER; BRUNDIN, 2020).

The PD is defined as a neurodegenerative disorder that affects predominately dopamine-producing (“dopaminergic”) neurons in a region of substantia nigra called *pars compacta*. The formation of Lewy body-related corpuscles at the central nervous system level causes dopamine deficits in the basal nucleus and causes non-motor symptoms such as constipation, depression, dementia, sleep problems, which may manifest themselves before motor impairment (CHAUDHURI; ODIN, 2010; SIMON; TANNER; BRUNDIN, 2020).

The PD cause motor symptoms such as postural instability, falls, fatigue, resting tremor, muscle stiffness, freezing of gait, bradykinesia, reduction of the range of motion, and dissociation of the trunk and hip (ZANARDI et al., 2021; KALIA; LANG, 2015; MONTEIRO et al., 2016b; SOARES; PEYRÉ-TARTARUGA, 2010). These symptoms impact functional mobility, reducing walking speed, step length, frequency, muscle activation, and increasing gait variability, energy expenditure. These alterations are associated with increased risk of falls and reduced activities of daily living and quality of life of this population (ZANARDI et al., 2021; KALIA; LANG, 2015; MONTEIRO et al., 2017; SOARES; PEYRÉ-TARTARUGA, 2010).

Although free walking (FW) is a functional activity, it is not characterized as an efficient type of locomotion due to the constant acceleration and deceleration of the body center of mass due to the frequent contact of the feet with the ground, which reduces the speed to zero in each step (SAIBENE; MINETTI, 2003). This interaction of the body with the ground represents a large part of the muscles' work to maintain locomotion (external mechanical work), to lift (vertical mechanical work) and accelerate horizontally (forward mechanical work) the body center of mass at each step (CAVAGNA; FRANZETTI; FUCHIMOTO, 1983; CAVAGNA; HEGLUND; TAYLOR, 1977; CAVAGNA; THYS; ZAMBONI, 1976). The external mechanical work at each step seems to be the primary responsibility for healthy people's energy expenditure (DONELAN; KRAM; KUO, 2002).

The pendulum-like mechanism (recovery) minimizes the mechanical work (and the chemical energy) produced by the muscles to move the body center of mass during walking due to kinetic and potential energies responses are fluctuating largely out-of-phase during the step (CAVAGNA; THYS; ZAMBONI, 1976). In healthy people, the greater recovery (≈ 65%) occurs at self-selected walking speed (~ 5km h^{-1}). The external mechanical work is minimal at these conditions, and the vertical and forward mechanical work are similar, resulting in lower energy expenditure (CAVAGNA; THYS; ZAMBONI, 1976). People with PD walking at self-selected walking speed (~3 km h^{-1}) do not change the recovery compared to healthy people, and the mechanical work is lower, even in advanced stages of PD (DIPAOLA et al., 2016).

The PD also impacts the vertical and anteroposterior GRF components, reducing braking components under time-critical conditions (BISHOP et al., 2003). Also, reduce the propulsive component of the anteroposterior force and the second peak of the vertical compared to healthy people (SHARIFMORADI; FARAHPOUR, 2016). These alterations are caused by disorders in lower limb muscle activity (ISLAM et al., 2020). Physical exercise is suggested as a strategy to aid in the drug treatment of PD impacting positively the neuropathology by increasing receptors on dopaminergic neurons (XU; FU; LE, 2019). In addition, aerobic exercises seems to be useful for improving gait, cardiovascular capacity, and medication effect (SOARES; PEYRÉ-TARTARUGA, 2010). The high-intensity multimodal (KELLY et al., 2017; LANDERS et al., 2019) and the stationary cycling (FIORELLI et al., 2019; JANSEN et al., 2021) exercise programs were previously reported as feasible and safe in PD. The variation of intensity increases substantia nigra amount and prefrontal brain activity (KELLY et al., 2017), cardiorespiratory fitness, balance, walking performance, motor symptoms, and quality of life (UHRBRAND et al., 2015).

The high walking speed is an important marker of the functionality and mobility of people with PD. Because it increases step length, step frequency, swing time and reduces double contact time and gait variability (PETERSON et al., 2020). Recent evidence has pointed out fast walking speed as a promising locomotor rehabilitation strategy (BALBINOT et al., 2020). Furthermore, Nordic running (NR) has been used previously in NW training programs for intensity modulation in PD (FRANZONI et al., 2018; ZANARDI et al., 2019), impacting positively the functionality. However, the fast-walking speed and NR method should be better understood to incorporate to training.

The NW is a type of locomotion that uses poles with contribution of the upper body limbs to the displacement of the body forward, which generates two propulsive actions in addition to the gait cycle (JENSEN et al., 2011; KLEINDIENST et al., 2006). The NW poles redistribute body weight and reduce overload on the lower limbs (KOCUR; WILK, 2006). The long step, initial contact in the ground with the heel, and higher range of trunk motion characterize the NW technique (ARCILA et al., 2017), based on the contralateral coordination between arms and legs (PELLEGRINI et al., 2015). The NW instructors increase pendular recovery and mechanical energy fluctuations, while the external mechanical work remains unchanged compared to FW (PELLEGRINI et al., 2017). However, the NW did not change the recovery and increase external mechanical work in the sedentary older people compared to FW (GOMEÑUKA et al., 2020). Therefore, these mechanical and pendular-like responses yet unknown in people with PD.

The NW postural balance (FRANZONI et al., 2018) increases walking ability compared to FW (BANG; SHIN, 2016), reducing the prevalence of gait freezing (WRÓBLEWSKA et al., 2019), and increasing step length (GOUGEON; ZHOU; NANTEL, 2017) in people with PD. The poles also increase the step frequency and fast walking speed, which induces reduced step length variability compared to FW (REUTER et al., 2011). The NW also increased the range of knee and hip movement and symmetry between the affected and non-affected sides, compared to FW (ZANARDI et al., 2019). All these changes collectively impact functional capacity and reduce motor symptoms (MONTEIRO et al., 2016a).

The NR is a similar modality that has been investigated in healthy people. This modality is suggested as an effective training method to reduce excessive overload of the lower extremities limbs during the stance and push-off phases, reduce injuries and increases safety while running in more challenging conditions (KŮTEK; TVRZNÍK, 2014; SUGIYAMA et al., 2013). However, to the best of our knowledge, biomechanical responses of NR in PD are unknown. Similarly, although the use of NW pole seems to be an effective strategy associated with drug treatment (CUGUSI et al., 2015), accessible and safe active to PD rehabilitation (WARLOP et al., 2017), the acute responses of the NW on spatiotemporal, mechanical work and kinetic parameters in people with PD are still unknown. These findings may aid explain the higher energy cost of PD locomotion (NARDELLO et al., 2017), which can positively impact the performance of daily living activities.

Furthermore, this study proposes to fill specific gaps in the literature on the use of NW poles in people with PD, avoiding the some limitations from previous studies such few gait speeds, treadmill trials, and age-matched control group (DIPAOLA et al., 2016; PELLEGRINI et al., 2017). Besides, we aimed to contribute to locomotor training and rehabilitation prescription in PD.

1.3 Aims

1.3.1 General aim

We aimed to compare mechanical parameters, pendulum-like mechanism, kinetic, and spatiotemporal variables of gait at different speeds with and without NW poles in people with PD and healthy controls.

1.3.2 Specific aims

- Compare the mechanical, pendulum-like, and spatiotemporal gait parameters at different speeds with and without NW poles in people with PD and healthy control.
- Compare the kinetic and spatiotemporal parameters at fast walking speed and running with and without NW poles in people with PD and healthy control.

1.4 Literature review

1.4.1 The gait physiomechanics of people with Parkinson's disease

1.4.1.1 Gait spatiotemporal parameters

Human walking is characterized by cycles that occur in a rhythmical and repeated pattern, beginning when the foot makes contact with the ground and ends at the subsequent instant the same foot makes contact with the ground. Thus, the walking cycle is divided in two phases: 1) the stance phase when the foot is in contact with the ground, and 2) the swing phase when the foot and leg swing forward to be placed in front of the body to begin another cycle (figure 1) (HUGHES; JACOBS, 1979).

The stance phase is about 60% of the cycle, while the swing phase is 40% at self-select walking speed (~ 4.3 km.h^{-1}), taking on inverse proportion with increasing speed (HUGHES; JACOBS, 1979; NILSSON; THORSTENSSON, 1989). The stance phase can be subdivided into five events; 1) initial contact; 2) load response; 3) mid-stance; 4) terminal support; and 5) pre-swing, which together perform the task of impact absorption, initial limb stability, sustain body weight and maintain progression (NILSSON; THORSTENSSON, 1989; PERRY; BURNFIELD, 2010). The swing phase is characterized by three events: 1) initial swing; 2) mid-swing; 3) terminal swing, which together perform the task of moving the foot forward in space, accelerating, decelerating and preparing to touch the ground, and start another walking cycle (HUGHES; JACOBS, 1979). The double stance period occurs when both feet are in contact with the ground simultaneously, and there are two double stance periods in each cycle, one at the beginning and one at the end of the stance phase (NILSSON; THORSTENSSON, 1989).

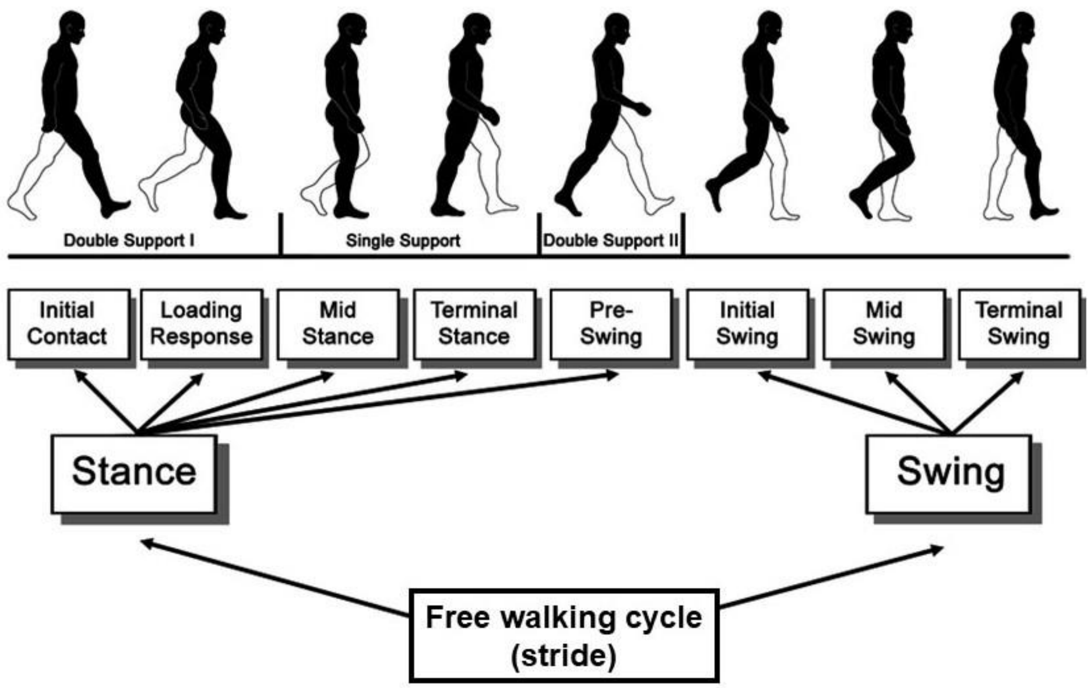

Figure 1 Free walking cycle (adapted from Stöckel et al., 2015).

Several factors can influence gaits, such as age, muscle strength, range of motion, speed of the movement and physical condition. The magnitude of the influence of these factors can be quantified to characterize a person's walking performance. These assessments allow characterizing a walking pattern composed by the spatiotemporal variables: step length, step frequency, walking speed and step width (SHANKMAN; MANSKE, 2014).

In general, the response of these parameters in healthy people of both sexes shows step length between 1.33 and 1.63 meters, self-selected walking speed about 5 $km.h^{-1}$, step frequency ranging between 107 and 125 steps per minute (SHANKMAN; MANSKE, 2014). Walking speed is the product of stride length and stride frequency, increasing or decreasing through these parameters. As speed increases, contact time is reduced relative to swing time. Thus these walking parameters mainly depend on speed (NILSSON; THORSTENSSON, 1989; SHANKMAN; MANSKE, 2014).

Monteiro et al. (2016) evidenced that the main spatiotemporal changes in the walking of people with PD are the step frequency and double stance time increased, and a reduced step length and walking speed. These changes lead to more significant variability at each step, which seems to be associated with a greater risk of falling.

Siragy and Nantel (2018), in a systematic review with 81 included studies, suggested that healthy adults can walk consistently (spatial variability), rhythmically (temporal variability) in a correlated pattern, leading to regular steps. However, in people with PD, these processes are damaged at a level beyond the effects of aging. For this reason, people with PD walk with greater spatiotemporal variability.

In line with finds from Monteiro et al. (2016) and Siragy and Nantel (2018), a recent systematic review and meta-analysis from Zanardi et al. (2021) with a total of 72 studies involving 3027 participants (1510 with PD and 1517 health control) showed that the self-selected walking speed, stride length, swing time, and hip excursion were reduced in people with PD compared with healthy control. These worst are associated with a high risk of falls and decrease life qualify.

The rehabilitation of these parameters is substantial because they impact the performance of activities of daily living of these people, as reported in recent studies by Amaral-Felipe et al. (2020) and Yamada et al. (2020). These authors compared the responses of spatiotemporal parameters of people with PD and healthy people in FW, dual-task, and traffic light crossing conditions, summarized in table 1.

Table 1 Spatiotemporal parameters gait and functionally.

Studies	Assessment	Groups	Condition	Outcomes
(YAMADA et al., 2020)	ground by electronic rug	PD = 20 HC = 20	1 - walking without additional task in SSWS	↓WS, SF, SL, #SW, DST, ST, CT.
			2 - walking while carrying bags with weight (10% of their body weight)	↓WS, SF, SL, ST. ↑DST
			3 - walking while talking on the cell phone	↓WS, SF, SL, ST. ↑DST, CT.
(AMARAL-FELIPE et al., 2020)	ground by electronic rug	PD = 20 HC = 20	1 - Street crossing in SSWS	↓WS, SL. ↑DST
			2- Street crossing simulation with pedestrian traffic light programmed for 8 s (4.32 $km.h^{-1}$)	↓WS, SL.
			2 Street crossing simulation with pedestrian traffic light programmed for 6 s (5.76 $km.h^{-1}$)	↓WS

Self-select walking speed (SSWS); Parkinson group (PD); healthy control (HC); greater for Parkinson group (↑); lower for Parkinson group (↓); remains similar (#); walking speed (WS); step frequency (SF); step length (SL); step width (SW); double stance time (DST); swing time (ST); contact time (CT); seconds (s).

Thus, it is observed that walking speed is an essential component of spatiotemporal variables, and it is currently a considerable predictor of mobility, functionality, and mortality, and notably affected in people with PD (PETERSON et al., 2020).

In general, people with PD show more pronounced differences compared to healthy control at a self-selected speed. This difference tends to decrease, while the strategy used by people with PD to reach and maintain fast speeds seems to increase the step frequency. However, some of the symptoms seem reduced at fast speeds (fast walking speed and sprint). Given the literature analyzed, it is still unclear the impact of the faster speeds on PD gait.

Some limitations were observed in the literature when PD gait was analyzed. Part of these studies used inertial sensors and accelerometers in assessments. Nevertheless, systematic reviews by Brognara et al. (2019) and Gondim et al. (2020) evidenced respectively, lack of agreement, lacking precision, and accuracy of these types of devices in the evaluations of spatiotemporal parameters. Furthermore, other studies have evaluated people only in treadmill conditions. However, in the investigations of Steib et al. (2019), it was noted that the effects of interventions on spatiotemporal parameters performed on a treadmill have limited transfer to overground walking conditions.

1.4.1.2 Mechanical parameters

Walking at constant speed consists of cycles (steps and strides) in which the mechanical energies (kinetic and gravitational potential) oscillate between their maximum and minimum values. At the same time, the body center of mass oscillates using force applied to the ground. This interaction of the body with the ground represents a large portion of the total mechanical work that muscles need to perform at each step to maintain locomotion (external mechanical work). Also, to lift against the action of gravity (vertical mechanical work) and to accelerate the body center of mass in forward direction (forward mechanical work) (CAVAGNA; HEGLUND; TAYLOR, 1977; CAVAGNA; THYS; ZAMBONI, 1976).

The mechanism adopted by humans to maintain motion at constant walking speed involves exchanges between mechanical energies at each step, and walking can be described as a rolling egg or the swing of an inverted pendulum. The amount of mechanical energy that muscles need to provide to maintain motion is reduced by increasing this interchange. It depends on the phase relationship magnitude and the degree of symmetry between the mechanical energies (CAVAGNA; SAIBENE; MARGARIA, 1963; CAVAGNA; THYS; ZAMBONI, 1976). Thus, the amount of work required to maintain a constant walking speed depends on the mechanical energy fluctuations (CAVAGNA; HEGLUND; TAYLOR, 1977).

In Cavagna, Thys, and Zamboni's (1976) study with healthy young men evaluated the walk on force platforms at speeds of 2 to 7 $km.h^{-1}$, the authors found that the amount of mechanical work is speed dependent. The results suggested that minimum external mechanical work is done at self-selected walking speed (~ 5 $km.h^{-1}$), the vertical mechanical work equals the forward mechanical work. Thus, kinetic and gravitational potential energies fluctuate out phase. However, the mechanism is affected by extreme speed conditions (~ 2 $km.h^{-1}$) the vertical mechanical work is greater than the forward mechanical work, indicating that the maximum kinetic energy occurred after the minimum gravitational potential energy. Similarly, at high walking speeds (~ 7 $km.h^{-1}$), the forward mechanical work is large than the vertical mechanical work. Indicating that the maximum kinetic energy occurred before the minimum gravitational potential energy, both extreme speed conditions (low and high) increase the external mechanical work.

The mechanical work of walking in people with PD was studied by Dipaola et al. (2016), in which 23 people with PD (Hoehn and Yahr, H&Y stage 2) and ten healthy controls were evaluated overground using kinematics parameters at similar speeds (self-selected for PD group and slow for healthy control). The results indicated that people with PD have lower total mechanical work and no vertical and forward mechanical work differences than healthy control. Furthermore, in the same study, vertical, forward, and total mechanical work are reduced at more advanced stages of the disease than people with PD at different stages of the disease (moderate and severe) and healthy control at similar walking speeds (slow).

The findings of Dipaola et al. (2016) agree partly with Gigot et al. (2016), who studied eight people with PD (Unified Parkinson’s Disease Rating Scale motor part – III, UDPRS – III = 42) and ten healthy people of both genders, was evaluated on force platforms while performing the Time Up and Go test. The authors found no differences in external mechanical work between the groups. Similarly, Kuhman, Hammond, and Hurt (2018) evaluated the walk of 15 people with PD (UDPRS – III = 31.3) and 15 healthy controls by kinematic during self-selected and fast walking speeds over the ground. The authors observed that total and joint (waist, knee, and ankle) mechanical work appeared to be reduced in people with PD at fast-walking speed compared to healthy control. The mechanical work reduces probably due to rigidity from PD. This reduction could impact pendulum-like energy recovery and aid in explaining the energy expenditure. However, it is still unknown.

Furthermore, recent literature reports significant evidence regarding the effect of speed on spatiotemporal, functional, mechanical, and pendulum-like parameters of people with PD compared to healthy control, compared at similar speeds (self-selected and fast gait speed), as summarized in table 2.

Table 2 Spatiotemporal gait and mechanical work and pendulum-like recovery parameters.

Studies	Assessment	Speeds	Groups	Outcomes
(PETERSON et al., 2020)	ground by an inertial sensor	SSWS for HC FWS for PD	PD = 67 HC = 40	**PD** ↑ WS, SL, SF, ST ↓ STV, DST **PD x HC** #WS, ST, STV, DST ↑ SF ↓ SL
(DIPAOLA et al., 2016)	ground by kinematic	slow for CS SSWS for PD	PD = 23 HC = 10	**PD X HC** #WS, SL, R ↓ W_{tot}
(KUHMAN; HAMMOND; HURT, 2018)	treadmill by kinematic	FWS	PD = 13 HC = 12	**PD x HC** ↓ W_{tot}
(CANNING et al., 2006)	ground by electronic rug	FWS	PD = 16 HC = 22	**PD x HC** ↓ WS, SL #SF
(PASSOS-MONTEIRO et al., 2020)	ground by kinematic	*Sprint*	PD = 16 HC = 21	**PD x HC** ↑Force ↑Power #S
(PENN et al., 2019)	nonmotorized treadmill by kinetic (force sensor)	FWS	PD = 12 HC = 13	**PD x HC** ↑SF

SSWS = self-select walking speed; FWS = fast walking speed; sprint = running with maximum effort; S =speed; PD = Parkinson group; HC: healthy control; ↑ = greater for Parkinson group; ↓ = lower for Parkinson group; (#) = remains similar; S = speed; WS = walking speed; SF = step frequency; SL = step length; SW = step width; DST = double stance time; ST = swing time; STV= step time variability; DST = double stance time; Wtot = total mechanical work; R = recovery.

1.4.1.3 Pendulum-like parameters

The motion of the body's center of mass during human walking resembles a square wheel because, at each step, kinetic energy is converted into gravitational potential energy and vice versa. So, the muscles need to perform work only to supply part of the mechanical energy lost during the step (CAVAGNA et al., 2002). Thus, muscle contractions use chemical energy to complete the external mechanical work done during the walking cycle. Nevertheless, almost no additional energy would be required to maintain a constant forward speed, whether decrements from potential energy, as the body center of mass reduces height, and decrements in kinetic energy, as the body center of mass decelerates with each step. It could be stored and used to reaccelerate and lift again during the other step (CAVAGNA; HEGLUND; TAYLOR, 1977).

The pendulum-like energy recovery represents precisely the mechanism of storage and release of mechanical energy at each step. It is optimization minimizes the metabolic energy required to produce the external mechanical work during human walking (CAVAGNA; HEGLUND; TAYLOR, 1977). Therefore, the fluctuating mechanical energies phase is a factor that can influence recovery. Typically, the phase is determined by the peaks of fluctuating energies, in the same direction pattern (in-phase) indicating a smaller recovery pendular, and opposite direction pattern (out-of-phase) indicating a high recovery pendular (BISHOP; PAI; SCHMITT, 2008).

In the healthy people, the maximal recovery (~ 65%) was found at intermediate speeds (~ 5 km.h^{-1}). As previously described, in these conditions, there was minimal external mechanical work and lower energy expenditure. However, the mechanism is impaired by extreme speeds, at nearly 2 km.h^{-1} recovery is reduced (~ 33%), and at high speeds, at nearly 7 km.h^{-1} recovery is also reduced (~ 21%) (CAVAGNA; THYS, AND ZAMBONI, 1976).

Dewolf et al. (2017) found similar results in healthy young men and women evaluated on a treadmill at seven walking speeds between 2 and 8 km.h^{-1}. They reported that the greater recovery (= 68%) was reached at speed around 5 km.h^{-1}, in which condition, the amplitude of kinetics and gravitational potential are approximately similar. On the other hand, at low speeds (< 5 km.h^{-1}), the magnitude of gravitational potential energy is greater than kinetic energy. The minimum gravitational potential energy precedes the maximum kinetic energy, yielding recovery lower than 60%. As expected at high speeds (> 5km.h^{-1}), the magnitude of gravitational potential energy is lower than kinetic energy. The minimum gravitational potential energy occurs after the maximum kinetic energy, producing recovery values below 50%.

Similar results were found by Gomeñuka et al. (2014) in healthy young people, evaluated on a treadmill by kinematics, in which the maximum recovery was reached at 5 km.h^{-1}. Dipaola et al. (2016) studied the pendulum-like energy recovery in people with PD, the authors evaluated 23 people with PD (H&Y stage = 3) and ten healthy controls of both sexes on the ground by kinematics. The recovery remained unchanged in PD people compared to controls at similar speeds. The authors suggested that the pendulum-like energy recovery as an effective way to reduce the energy expenditure of walking, are still maintained in people with PD in advanced stages.

1.4.1.4 Kinetic parameters

The interaction between the body and the ground during gait produces the vertical and anteroposterior components of the GRF. The vertical reaction force when walking typically shows two peaks with an interjacent valley. The curve of the anteroposterior reaction force has a braking force valley directed backward that has become a propulsive horizontal force at after mid-support (NILSSON; THORSTENSSON, 1989).

As walking speed increases, the GRF components are altered in healthy people. The periods of force application become short. The first and second vertical peak force is approximately equal, and the vertical valley force decrease progressively. The horizontal peak force (braking and propulsive) increased linearly with speed. The total vertical impulse decreases and the braking and propulsive impulse are approximately equal and take an inverted u-shape, and at high speed, the propulsive became large (NILSSON; THORSTENSSON, 1989).

The GRF components are important outcomes and have been widely used as a tool for diagnosis gait disorders and monitoring effectiveness of therapy post-diagnostic in PD (ALAM et al., 2017; DUBEY; WADHWANI; WADHWANI, 2013; MINAMISAWA et al., 2012; ŠVEHLÍK et al., 2009; VEERARAGAVAN et al., 2020). The literature reported alterations on the GRF components that characterize the PD. Bishop et al. (2003) studied 14 people with PD in self-select walking speed by force platforms. It was found that PD people (H&Y stage = 2.5) reduce generate sufficient braking components under time-critical conditions compared to healthy control.

Sharifmoradi and Farahpour (2016) evaluated the gait of 14 people with PD (H&Y stage = 2.5) in self-selected walking speed using force platforms. The results suggested reduces the terminal stance peak force and propulsive peak force components compared to healthy control. The authors suggested it decreased significantly due to ankle plantar flexor performance, which decreased in PD group. Sofuwa et al. (2005) evaluated 15 people with PD (H&Y stage = 2.5) during self-selected walking speed using force platforms and found a reduction in terminal stance components compared to healthy control. This result suggests that peripheral and central factors can contribute to a lack of forward progression.

The same results from Sofuwa et al. (2005) corroborated with found by Švehlík et al. (2009) that evaluated 20 people with PD (H&Y stage = 2.5) with a similar setup study. The authors reported that this reduction of terminal stance was an important mechanism contributing to the decreased walking speed of PD people. The GRF alterations, due to disorders in muscle activity of the tibial anterior and reduced performance of the gastrocnemius in PD (ISLAM et al., 2020). Furthermore, studies on the responses of the components during fast-walking speed are still limited in the literature. To our knowledge, they have not yet been described, so we do not know whether these changes are maintained at higher speeds.

1.4.2 Locomotion with poles and Parkinson’s disease

1.4.2.1 Physiomechanics of Nordic walking and Parkinson's disease

The NW is a physical activity in which FW is enhanced by adding the active use of a pair of specific design-built poles. However, the natural characteristics, biomechanics, and correct posture of FW are preserved. Furthermore, NW allows the active participation of the upper limbs in the walking dynamics to push the body forward, and the physical effort is distributed to several muscle groups throughout the body (GOMEÑUKA et al., 2020).

The NW technique is characterized by two phases (figure 2): 1) contact phase: it is the time during which the poles are in contact with the ground, this phase includes the impact and propulsion (RUSSO; MOCERA; SOMÀ, 2020), 2) loading phase: it is the time in which the poles are being pushed forward, preparing a new contact phase (ARCILA et al., 2017; KOCUR; WILK, 2006).

The upper body movement occurs in the vertical plane. It starts, 1) with the flexion of the shoulder and elbow joints at the level of the iliac crest, with simultaneous grip on the handle of the poles in preparation for the impulsion phase (KOCUR; WILK, 2006), 2) extension of the shoulder joint and elbow and unloading of the weight on the poles to propel the body forward (ARCILA et al., 2017). Then, 3) opening the hand and releasing the pressure on the baton, positioning the baton backward for the loading phase, which will later return to the hand due to the wrist fixation glove before the start of a new impulsion phase (KOCUR; WILK, 2006; PELLEGRINI et al., 2018).

A long step characterizes the NW technique, an initial contact on the ground with the heel, vertical stretching of the trunk (ARCILA et al., 2017), based on the contralateral coordination between arms and legs (PELLEGRINI et al., 2015). The pole is placed on the ground on the side contralateral to the advanced foot and diagonally to the back foot (FUJITA et al., 2018), approximately half of the step (KOCUR; WILK, 2006). During the impulsion phase, the poles of the ipsilateral side should be placed between the advanced lower limb of the contralateral side, proximally at mid-step. The fixing of the poles on the ground must be at sharp angles (angles less than 90°), never near the vertical position (approximately 90°) (KOCUR; WILK, 2006).

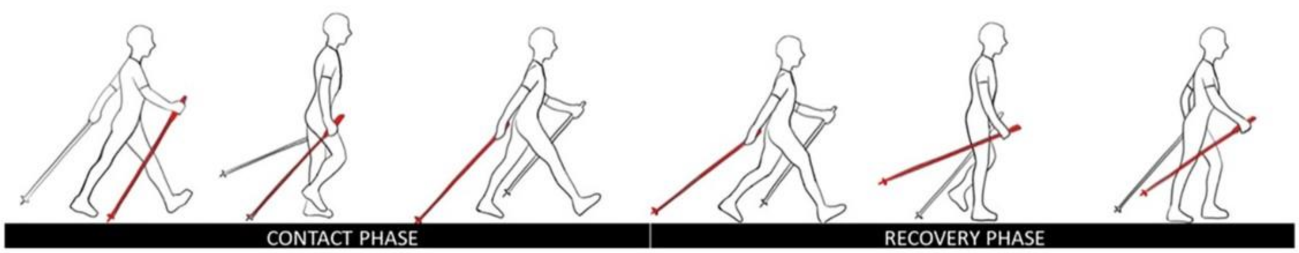

Figure 2 Phases of the Nordic walking (from Russo, Mocera e Somà, 2020).

The main difference between NW to FW is the collaboration of the upper body. The activating muscles act passively during FW, unload the lower limbs overexerted during FW (KOCUR; WILK, 2006). The NW technique contributes to the upper limbs to aid in pushing the body forward, which yields two additional propulsive actions to the FW cycle (JENSEN et al., 2011; KLEINDIENST et al., 2006). Furthermore, the active participation of the arms handling the poles against the ground provides a stable base of support that allows stabilizing the trunk (FRANZONI et al., 2018; GOUGEON; ZHOU; NANTEL, 2017). In NW instructors, walking with poles may reduce the effort to control trunk oscillations and may contribute to work produced during the NW (PELLEGRINI et al., 2015). Besides, a possibility of rehabilitation on hypokinetic and variability of PD gait could be characterized by rhythmic movements upper body during NW (WARLOP et al., 2017).

Bombieri et al.(2017) in a systematic review and meta-analysis with a total of 127 people, observed the effects of NW training programs in people with PD (H&Y stage = 2). The results suggest that NW increases walking ability, increases step length, reduces gait variability, increases self-selected speed compared to FW. However, the authors suggest that more evidence is still needed before NW can be widely recommended for people with PD, as significant limitations and lack compare NW with FW.

In line, Gougeon, Zhou, and Nantel (2017) found improvement in spatiotemporal parameters after a six-week NW intervention in 12 people with PD (H&Y stage = 2) of both sexes, without a control group, and compared the people' walking with and without poles by accelerometer. The results suggested that NW compared to FW, increased stride length, while self-selected walking speed and step frequency remain similar. Similarly, Warlop et al. (2017) evaluated the self-selected walking speed on the ground with and without poles of 14 people with PD (H&Y stage = 2) and ten healthy controls using accelerometer. The authors reported that NW reduced gait variability, increased stride length, and reduced stride frequency, with no change in self-selected speed compared to FW. In healthy control, there were no significant differences between FW and NW.

The results from Warlop et al. (2017) corroborated with Zhou, Gougeon, and Nantel (2017) who evaluated a six-week NW intervention program in 12 people with PD (H&Y stage = 2) and 12 healthy controls of both genders. The people were evaluated on the ground with poles and without poles by force platforms. The authors found that NW in people with PD increased step length and contact time to FW, with no difference compared to healthy control. In addition, the step frequency was reduced for NW compared to FW and healthy control. Another outcome was that the self-selected walking speed remains similar between the NW and FW conditions and between the groups.

The literature reviewed has not yet reported evidence on the mechanical parameters (vertical, forward, external mechanical work) and pendular mechanism of the NW in people with PD. A study by Gomeñuka et al. (2020), in which an eight-week aerobic training program was carried out in 33 sedentary older people (16 trained by NW and 17 by FW), showed that at a speed of 5 $km.h^{-1}$, FW reduced the external mechanical work and maintained the recovery to the baseline. However, the NW group at 5 km.h^{-1} maintained the external mechanical work and recovery. On the other hand, NW and FW increased the self-selected speed and reduced the metabolic cost in the post-training similarly.

During NW, people with PD appear not to increase energy expenditure at different walking speeds, as Nardello et al. (2017) reported. The authors investigated 20 people with PD (H&Y stage 3) and 20 healthy controls from both sexes in a treadmill with and without NW poles. The results suggested that during the NW at (2.5, 3.5, and 4.5 km.h^{-1}), only healthy control showed higher energy expenditure, and people with PD remained similar. Thus, the authors believed that no increase in exercise intensity during NW might have been due to poor execution of the technique. On the other hand, proper training in NW poles could increase energy expenditure in PD people, similar to healthy people.

The movement dynamic use poles count with applied force to pushing the body forward. The GRF components were studied by Encarnación-Martínez ; Pérez-Soriano; Llana-Belloch (2015) in 20 NW instructors during self-select walking speed using forces platform. The authors observed higher vertical and anteroposterior components (peak force and braking) at the touch-down compared with FW. However, they reduced the vertical force and anteroposterior (peak force and propulsive) at the take-off compared to FW. The same study showed that this pattern is maintained from self-select walking speed to fast-walking speed. It might be interpreted that the increase in speed is caused in part by a more dynamic use of the poles, resulting in a reduction of the parameters related to take-off. These findings are supported because the use of NW poles reduces muscle activity in the lower limb extremities during the touch-down. However, during take-off phases increase the upper body's energy expenditure and decrease the lower limb extremities (SUGIYAMA et al., 2013). The GRF parameters from poles in people with PD could provide information on stability and propulsion in Parkinson's gait, perhaps being a possibility to compensate for disorders in gastrocnemius and tibialis anterior activity (ISLAM et al., 2020).

The Encarnación-Martínez; Pérez-Soriano; Llana-Belloch (2015) finds are in line with Hagen; Hennig; Stieldorf, (2011) that studied 24 young NW instructors from both sexes during fast-walking speed assessment with accelerometer. The authors reported increased vertical peak force at the touch-down and reduction at the take-off. In addition, the anteroposterior peak force decreased at the touch-down. In contrast, Wilson et al. (2001) studied 13 healthy people with no experience walking poles by forces platform. The results showed to reduce the average vertical peak force and propulsive impulse. In addition, increase in braking impulse of the GRF compared to FW, and also, observed that different NW technics could increase vertical peak force and propulsive impulsive.

The responses of the GRF components could aid in understanding the propulsion and stability adjust during PD locomotion and whether use pole impacts motor symptoms. However, we did not find studies that evaluated the GRF responses in people with PD. In summary, the responses spatiotemporal temporal (walking speed, step frequency, and contact time), mechanical work (vertical, forward, and external), and pendulum-like mechanisms (recovery) in people with PD during NW still unknown.

1.4.3 Physiomechanics of Nordic running and Parkinson's disease

The running cycle starts when one foot makes contact with the ground and finishes when the same foot makes contact again (touch-down). The stance finishes when the foot has left contact with the ground (take-off), which indicates the start of the swing phase of the gait cycle. Each phase is subdivided following as 1) stance phase absorption; stance phase generation; 3) swing phase generation; 4) swing phase reversal; 5) swing phase absorption. Also, there are two periods during the running cycle when both feet are airborne (double float), one at the beginning and one at the end of swing (NOVACHECK, 1998).

In healthy people, as increase of speed the swing time and double float increases, while the stance time and cycle time decreases (NOVACHECK, 1998). At low speed, the step length is the main responsible for increasing the speed, and the step length is primary at high speed (BAILEY; MATA; MERCER, 2017). This pattern occurs because less energy is expended by increasing the step length than the step frequency (CAVANAGH PR, KRAM, 1989).

The responses of the GRF of the healthy people during free-running demonstrated an increase in the vertical peak force, the peaks in braking, and propulsive as the speed increases, while the total vertical impulse reduces with increased speed (NILSSON;

THORSTENSSON, 1989). Regarding to braking and propulsive impulses have similar proportions to each other. Interesting, although braking and propulsive impulses must be equal for constant horizontal speed, the reaction force pattern difference in the anteroposterior direction could be expected (NILSSON; THORSTENSSON, 1989). The propulsive impulse tends to be large to overcome external restrictions, for instance, air resistance, and previous studies reported that the energy cost of overcoming air resistance in track running may be 7.5 % of the total energy cost at middle distance speed (PUGH, 1971). On the other hand, the reduction of the braking impulse to be associated with smaller step length, the distance of foot placement in front of the body (NILSSON; THORSTENSSON, 1989). To our knowledge, the GRF response from free running in people with PD still unknown.

The NR is a similar modality that has been investigated in healthy people. Furthermore, it is training method has been suggested to reduce the excessive overload of the lower extremities limbs during the stance and push-off phases, reduce injuries and increase safety while running in more challenging conditions (KŮTEK; TVRZNÍK, 2014; SUGIYAMA et al., 2013).

Kwon, Bolt, Shim (2001) investigated ten male recreational NR at 13 $km.h^{-1}$ over the ground by a force platform. The authors find that poles affected the take-off, decreasing both peak vertical propulsive force and vertical impulse. The same study also showed that the running poles altered the lower limb kinematics during the swing phase by decreasing the knee range of motion and increasing the maximal hip extension. These find agreed with Daviaux et al. (2013) studied ten healthy men NR at 13 $km.h^{-1}$ over the ground by sensors measuring pressure. They observed that using poles during running reduced plantar forces, suggesting that poles can redistribute mechanical work between limbs.

The NR and the NW are based on the contralateral coordination between arms and legs, where the pole held on the opposite side of the stepping foot is planted diagonally backward (PELLEGRINI et al., 2018). The NR technique is characterized by stance prolonged during the swing phase, different from free running. 1) the poles accelerate during the all-swing phase; 2) the stance arm ends the take-off near the hip with the elbow slightly flexed. 3) the arm's push follows according to the duration of the swing phase, which allows the full extension of the elbows. 4) in the second half of the swing phase, the leg swings forward and prepares for foot contact (KŮTEK; TVRZNÍK, 2014).

To our knowledge, there is a lack of literature that targeted investigate free running and NR in people with PD. The high-intensity multimodal (KELLY et al., 2017; LANDERS et al., 2019) and stationary bicycle (FIORELLI et al., 2019; JANSEN et al., 2021) exercise programs were previously reported as feasible and safe in PD. High-intensity exercise may have beneficial effects on PD, increase substantia nigra and prefrontal brain activity (KELLY et al., 2017), and improve cardiorespiratory fitness, balance, walking performance, motor symptoms, and quality of life (UHRBRAND et al., 2015). Furthermore, NR has been used previously in NW training programs for intensity modulation in PD (FRANZONI et al., 2018; ZANARDI et al., 2019), with functional improvement. Nevertheless, the method of running with poles should be better understood to be incorporated in training. However, the evidence is yet limited. The responses description of the GRF components could use to understand stability and propulsion adjustments PD locomotion, and certify the safety of running with and without poles.

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CHAPTER 2

BIOMECHANICAL RESPONSES OF NORDIC WALKING IN PEOPLE WITH PARKINSON’S

Abstract

Background: In healthy adults, Nordic walking (NW) is known to maintain external work in comparison to free walking (FW) because pendulum-like recovery is improved when using poles. **Objective:** We aimed to compare mechanical, pendulum-like, and spatiotemporal parameters of gait at different speeds with and without NW poles in people with Parkinson’s disease and healthy controls. **Methods:** The study included 11 people (aged 65.6±7.0 years) with idiopathic Parkinson’s disease, scoring between 1 and 1.5 on the Hoehn and Yahr scale (H&Y), and nine healthy controls (aged 70.0±5.6 years). All the people were experienced Nordic walkers. Data was collected with people walking at two speeds, 1.8 km.h^{-1} and 4.7 km.h^{-1}, on eight 3D force platforms on a walkway. **Results:** We found greater pendulum-like energy recovery ($p<0.05$) in the Parkinson’s group during NW than in FW, while external mechanical work remained similar ($p>0.05$). People with Parkinson's disease showed a major increase in vertical and forward energy fluctuations using poles than in healthy controls. In addition, the Parkinson’s group showed increased step frequency and reduced step length compared to controls in the NW and FW conditions. Our findings partly justify the lower walking economy in Parkinson's disease due to higher total work and reduced pendulum-like mechanism at commonly used speeds. NW alters gait mechanics similarly in Parkinson’s group and healthy control, increasing the total work due to internal work. **Conclusion:** Therefore, NW can be a compelling strategy for rehabilitation because of its potential for improving functional mobility, increasing pendulum-like energy recovery, and increasing external mechanical work in Parkinson's disease.

Keywords: Parkinsonism; gait, stick; mechanical energy, recovery.

2.1 Introduction

Parkinson’s disease (PD) causes motor symptoms such as postural instability, resting tremor, muscle stiffness, and bradykinesia (ZESIEWICZ, 2019).These alterations reduce walking speed and step length (ZANARDI et al., 2021) while increasing gait variability (PLOTNIK; GILADI; HAUSDORFF, 2007) and energy expenditure (NARDELLO et al., 2017), which are collectively associated with an increased risk of falls, reduced activities of daily living, and reduced quality of life (NIJHUIS et al., 2021). Although free walking (FW) is a functional activity, it is not characterized as an efficient type of locomotion because of the constant acceleration and deceleration of the body’s center of mass due to the frequent contact of the feet with the ground, which reduces the speed to zero in each step (SAIBENE; MINETTI, 2003). This interaction of the body with the ground represents a large part of the work that the muscles need to do to maintain locomotion (external mechanical work), lift (vertical mechanical work), and horizontally accelerate (forward mechanical work) the body’s center of mass at each step (CAVAGNA; HEGLUND; TAYLOR, 1977; CAVAGNA; THYS; ZAMBONI, 1976). The external mechanical work at each step seems to be the major factor responsible for energy expenditure in healthy people (DONELAN; KRAM; KUO, 2002). The magnitude of the transfer between these external energies is quantified by the pendulum-like recovery, an energy expenditure saving mechanism, which reduces the chemical energy used by the muscles to move the body’s center of mass (CAVAGNA; THYS; ZAMBONI, 1976). In healthy people, a high recovery (~ 65%) occurs at a self-selected walking speed (~ 5 $km.h^{-1}$). Under these conditions, the external mechanical work is minimal, the vertical and forward mechanical work are similar, and the time of the upward and downward displacement of the body’s center of mass is symmetrical (CAVAGNA; LEGRAMANDI, 2020). These mechanical aspects enable a reduction in the metabolic energy expenditure (CAVAGNA; THYS; ZAMBONI, 1976).

Aside from its benefits to neuropathological aspects, physical exercise is a strategy to aid drug treatment and reduce the harmful effects of PD because it increases the receptors of dopaminergic neurons (XU; FU; LE, 2019). Aerobic exercise appears to improve gait, cardiovascular capacity, and drug effect (LI et al., 2021). Nordic walking (NW) is a type of physical activity that uses a specifically designed pole, with the contribution of the upper body limbs to aid in the displacement of the body moving forward, which generates two propulsive actions in addition to the gait cycle, redistributing the body weight and decreasing the load on the lower limbs (KOCUR; WILK, 2006). The NW technique is characterized by a long step, initial contact of the ground with the heel, and a higher range of trunk motion (ARCILA et al., 2017), due to the contralateral coordination between the arms and legs (PELLEGRINI et al., 2015). Previous studies investigated adaptation at different speeds and suggest that NW may be effective in several aspects of the Parkinson's gait as it improves postural balance (FRANZONI et al., 2018), increases self-select walking speed compared to FW (MONTEIRO et al., 2016a), and increases step length (GOUGEON; ZHOU; NANTEL, 2017). In addition, it increases the maximum walking speed and induces a reduction in step length variability compared to FW (REUTER et al., 2011), increasing the total range of motion of the knee and hip movement and the symmetry between the affected and non-affected sides (ZANARDI et al., 2019). All these changes have a collective impact on improving functional capacity and reducing motor symptoms (MONTEIRO et al., 2016a).

Therefore, NW seems to be an effective, accessible, and safe strategy associated with drug treatment of PD (CUGUSI et al., 2015). Even so, there is scant literature discussing locomotion in Parkinson's based on gait parameters and mechanical energies through the use of acute NW poles. To our knowledge, the acute effects of the poles have been investigated only unaffected male NW instructors, and these results indicate increased mechanical energy fluctuations and pendulum-like recovery with similar external mechanical work compared to FW (PELLEGRINI et al., 2017). Thus far, gait of people with PD has only been studied without the use of poles, with these people being compared to healthy people at self-selected walking speeds. These findings have indicated similar recovery and lower mechanical work between PD people and healthy controls, even in advanced stages of the disease (DIPAOLA et al., 2016). The acute responses of NW to spatiotemporal and mechanical work parameters in this population are still unknown. In addition, pendulum-like mechanism analysis is important because it reflects the reduction in muscle effort needed to accelerate and elevate the body's center of mass during walking, which can improve patient performance in activities of daily living (CAVAGNA; HEGLUND; TAYLOR, 1977). Moreover, it has been suggested that metabolic cost in people with PD does not increase during NW when compared to FW (NARDELLO et al., 2017).

Many previous studies have examined the effect of NW in PD people after a training program. Several studies have evaluated walking trials in treadmill conditions, and modifications are expected in gait parameters when compared to overground conditions (CAVAGNA; HEGLUND; TAYLOR, 1977; ZANARDI et al., 2021). In addition, fewer ecologic trials are performed without walking poles (NARDELLO et al., 2017; PELLEGRINI et al., 2017). We aimed to compare mechanical work, pendulum-like recovery, and spatiotemporal parameters of gait with and without NW poles between people with PD and healthy controls at different speeds. We hypothesized that the use of NW poles would increase recovery and decrease external mechanical work compared to FW at all walking speeds in people of both groups. It was also expected that the use of NW poles would increase the step length and decrease the step frequency at all speeds compared to the FW condition in people with PD.

2.2 Materials and methods

2.2.1 Subjects and ethics statement

This was an observational study with nonprobability sampling. All participants were aware of the conditions and procedures of the study before signing their consent to participate. This study was approved by the Ethics Committee of Research (omitted for peer review). The experiments were conducted with 11 voluntary people of both sexes aged over 50 years diagnosed with stage 1 or 1.5 of idiopathic PD based on the modified Hoenh and Yahr (H&Y) scale (Table 1) and who were all experienced Nordic walkers with at least 6 months of experience. They had to be able to walk independently on a walkway with and without poles. The people performed the protocol while they were in their “ON” period of medication, no later than three hours after ingestion of drugs, and at least one hour prior to the protocol test. Nine healthy people also participated in this study with the same eligibility criteria (except H&Y scale). The exclusion criteria for both groups were: a history of respiratory and cardiovascular diseases, musculoskeletal injuries, previous surgeries, labyrinthitis in the last year, prosthesis users of both upper or lower limbs, and inability to understand verbal commands and perform the test protocol. The sample size was calculated using GPower software (version 3.1) with a significance level of 5% and a power of 95%. The sample size was estimated using values of recovery, external mechanical work, vertical mechanical work, forward mechanical work, and step frequency, based on studies by Dipaola et al. (2016) (DIPAOLA et al., 2016) and Pellegrini et al. (2017) (PELLEGRINI et al., 2017).

2.2.2 Study design

The gait protocol consisted of three different days with a minimum interval of 48 h and a maximum of 72 h between days. Sample characteristics were evaluated on the first day. On the second day, the walking modality (FW and NW) and the order of walking speeds were first randomized using the Randomizer software (randomizer.com). Thereafter, a familiarization of walking on a walkway was executed for five minutes, followed by the walking tests for data collection. On the third day, a different modality from the second day was performed.

2.2.3 Data acquisition of ground reaction forces

Kinetic data were recorded using a three-dimensional ground reaction force (GRF) measurement system setup on a walkway (1.2 m wide × 6 m long) with eight built-in force platforms (INFINIT-T, BTS, Bioengineering, Italy) and a sampling rate of 1000 Hz. Data collection was managed using SMART Capture software (BTS, Bioengineering, Italy). Static calibration was performed before the walking tests, with the subject in the orthostatic position on a reference platform where we registered the body weight (Figure 3).

The people were evaluated during FW and NW at 1.8 km.h^{-1}, 4.7 km.h^{-1}, and a self-selected walking speed (only for sample characteristics). The NW pole length was determined as per recommendations by the International NW Federation, which is to multiply the subject's height in centimeters by 0.65, with a tolerance of ± 2.5 centimeters (NARDELLO et al., 2017). Moreover, for the NW condition, all people were asked to use the diagonal technique recommended by the International NW Federation, which is based on the contralateral coordination between arms and legs (PELLEGRINI et al., 2015).

Ten walking trials were performed at all speeds over the walkaway in both modalities (NW and FW) (WILLSON et al., 2001). After each trial, the people were asked to return to their initial position on the walkaway to continue the protocol. One minute of rest was adopted between trials and five minutes between the speeds (PASSOS-MONTEIRO et al., 2020). All speed conditions were controlled by a chronometer when people across markers were positioned before and after the force platforms. Verbal commands were used during the trials to maintain the people at the target speed. We analyzed the walking speed of each trial later using GRF data analysis.

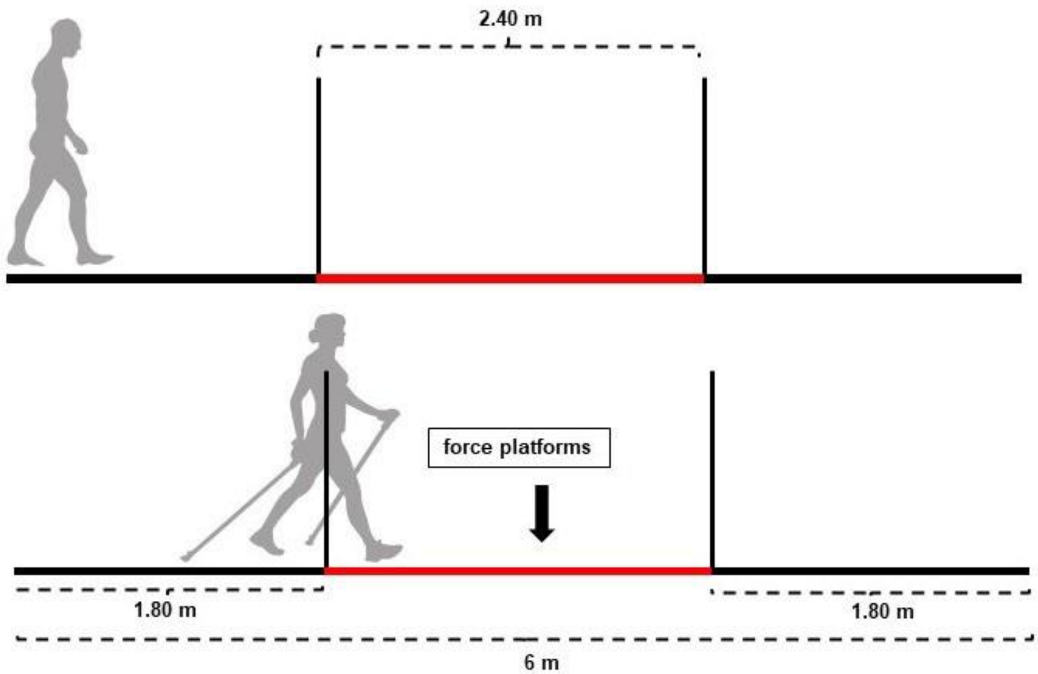

Figure 3 Experimental set-up of the free walking and Nordic walking

2.2.4 Mechanical work parameters

Mechanical work analyses were performed on the double stance phase (SCHEPENS et al., 2004). We defined the gait step starting at the heel-ground contact and ending at the subsequent ground contact of the contralateral heel. The steps were divided according to the maximum forward velocity (DEWOLF et al., 2017). The step was considered valid for analysis only when the subject walked at a relatively constant mean speed. Thus, the sum of the increments of the vertical velocity and the forward velocity of the body’s center of mass could not be greater than 25% of the decrements (CAVAGNA, 1975; SCHEPENS et al., 2004).

Acceleration, velocity, and displacement of the body's center of mass were determined from the forward and vertical components of the GRF. The lateral component was neglected because the vertical and forward work is approximately 100 times greater than the lateral work (CAVAGNA, 1975). The vertical and forward accelerations were calculated using the equation $F_v - BW = m.a_v$, $F_f = m.a_f$, where m is the subject's body mass, g is the gravitational acceleration, and BW is the body weight. The instantaneous vertical and forward velocities were computed by the integration of acceleration, plus an integration constant. The forward integration constant was equal to the average forward speed of the subject during each trial. The vertical integration constant was obtained by the ratio between the area below the vertical velocity tracing and the period of step, and the second integration of the vertical velocity produced the vertical displacement of the body's center of mass. Subsequently from the instantaneous velocity in the forward and vertical directions, we calculated the kinetic ($KE_f = 0.5mV_f^{\,2}$ and $KEv = 0.5\,mVv^{\,2}$), potential ($PE = mgh$), and total energies ($Etot = KE_f + KEv + PE$) associated with the body's center of mass, where m is body mass, V_f is the velocity of the component forward, Vv is the velocity of the component vertical, g is gravitational acceleration, and h is the height of body's center of mass.

The external mechanical work was determined by the sum of the positive increments in the total energy. The vertical mechanical work was determined by the sum of the positive increments of the potential gravitational and vertical kinetic energies. Forward mechanical work was determined by the sum of the positive increments of the forward kinetic energy curve. The magnitude of the transfer between the gravitational potential and kinetic energy was quantified by the percentage recovery (CAVAGNA; THYS; ZAMBONI, 1976) as follows:

$$R = 100 \times \frac{Wv + Wf - Wext}{Wv + Wf} \qquad \text{Equation 1}$$

The internal mechanical work was calculated using the experimental values of step length (L), average gait speed (V_f), and step frequency (f) using the equation by Cavagna et al. (CAVAGNA; LEGRAMANDI; PEYRÉ-TARTARUGA, 2008):

$$W_{int} = 0.140 \times 10^{-0.200L} \times V_f \times f \qquad \text{Equation 2}$$

2.2.5 Spatiotemporal parameters

The step length (*SL*) was obtained by multiplying the forward velocity (V_f) by the period of step (*T*) ($SL = V_f \, . \, T$). The step frequency (*SF*) was obtained using the inverse of the step period ($SF = 1/T$). The single stance was calculated as the fraction of the period during which only one foot contacts the ground and a double stance in which both feet contact the ground (CAVAGNA; THYS; ZAMBONI, 1976). The lateral and vertical oscillations were calculated as the difference between the maximum and minimum positions in both directions of the body's center of mass. All data were processed using Matlab 9.4 (MathWorks Inc., Natick, MA, USA) and Excel 2016 (Microsoft Corporation, Redmond, WA, USA).

2.2.6 Statistical analysis

All data are presented as the mean and standard deviation. The individual sample characteristics data were compared using an independent-sample t-test. The symmetry between the more and less affected sides in the Parkinson's group (ZANARDI et al., 2019) was evaluated using the paired-samples t-test. No difference between the more and less affected sides was observed when only one side was chosen. Generalized Linear Model was used to identify the main effects group (control × Parkinson's group), modality (FW × NW), and group × modality interactions, and Bonferroni post hoc was used to find statistical differences. We tested the gamma and linear distribution models and chose the model best fitted to the data, defined by the lowest Akaike's Information Criterion value. Statistical analysis was performed using the statistical software Statistical Package for Social Sciences (SPSS, Chicago, USA) v.26. The significance level was set to $\alpha = 0.05$.

2.3 Results

The sample characteristics are presented in Table 3. No significant differences were found between the healthy control and Parkinson's group for all variables except the self-selected walking speed with or without the use of poles.

Table 3 Sample characteristics

Variables	Healthy control	Parkinson group	p-value
Subject (male/female)	9 (5/4)	11 (6/5)	-
Age (years)	70.0 ± 5.6	65.6 ± 7.0	0.149
Height (m)	1.69 ± 0.07	1.63 ± 0.11	0.195
Weight (kg)	73.0 ± 10	71.1 ± 14.8	0.753
BMI	25.6 ± 3.4	26.5 ± 3.5	0.585
Disease Duration (years)	-	9.4 ± 6.4	-
UPDRS – III	-	11.6 ± 3.1	-
H&Y	-	1 ± 0.5	-
SSWS FW ($km.h^{-1}$)	3.96 ± 0.57	2.98 ± 0.42	**<0.001**
SSWS NW ($km.h^{-1}$)	3.87 ± 0.79	3.15 ± 0.68	**0.042**
Lower Limb Length (m)	0.90 ± 0.05	0.87 ± 0.05	0.262

The results for independent t-test comparing Healthy and Parkinson group. The self-selected walking speed was not affected by modality in the Parkinson group (main effect: $p = 0.467$) and healthy control (main effect: $p = 0.764$). Body mass index (BMI); Unified Parkinson's Disease Rating Scale motor part - III (UDPRS – III); Hoehn & Yahr scale (H&Y); free walking self-selected walking speed (SSWS FW); Nordic walking self-selected walking speed (SSWS NW). H&Y Values are presented by median and interquartile range, other values by average and standard deviation.

2.3.1 Spatiotemporal parameters

2.3.1.1 Step length

The step length was affected by group at 1.8 $km.h^{-1}$ and 4.7 $km.h^{-1}$ (main effect: $p < 0.001$ for both), and it was affected by modality at 1.8 $km.h^{-1}$ but not at 4.7 $km.h^{-1}$ (main effect: $p < 0.001$ and $p = 0.823$, respectively). Moreover, a significant interaction was identified at 1.8 $km.h^{-1}$ but not at 4.7 $km.h^{-1}$ (interaction effect: group x modality: $p < 0.001$ and $p = 0.795$, respectively). The step length for NW and FW in the Parkinson's group was lower than that in healthy controls at 1.8 $km.h^{-1}$ ($p < 0.001$ and $p < 0.047$, respectively). In healthy controls, step length for NW was greater than that for FW at 1.8 $km.h^{-1}$ ($p < 0.001$). In addition, step length was smaller in the Parkinson's group than in healthy controls at 4.7 $km.h^{-1}$ ($p = 0.001$; Table 4), independent of modality.

2.3.1.2 Step frequency

The step frequency was affected by group at 1.8 $km.h^{-1}$ and 4.7 $km.h^{-1}$ (main effect: $p < 0.001$ for both), and it was affected by modality at 1.8 $km.h^{-1}$ but not at 4.7 $km.h^{-1}$ (main effect: $p < 0.001$ and $p = 0.923$, respectively). Moreover, a significant interaction was identified at 1.8 $km.h^{-1}$ but not at 4.7 $km.h^{-1}$ (interaction effect: group x modality: $p < 0.001$ and $p = 0.780$, respectively). The step frequency for NW in the Parkinson's group was greater than the healthy controls at 1.8 $km.h^{-1}$ ($p < 0.001$). In healthy controls, step frequency for NW was lower than FW at 1.8 $km.h^{-1}$ ($p < 0.001$), while in the Parkinson's group it was greater than healthy controls at 4.7 $km.h^{-1}$ ($p < 0.001$; Table 4), independent of modality.

2.3.1.3 Vertical oscillation

At the speeds of 1.8 $km.h^{-1}$ and 4.7 $km.h^{-1}$, the vertical oscillation was not affected by group (main effect: $p = 0.190$ and $p = 0.619$, respectively), but it was affected by modality (main effect: $p = 0.024$ and $p = 0.001$, respectively). Moreover, a significant interaction was not identified at either speed (interaction effect: group × modality: $p = 0.477$ and $p = 0.866$, respectively). The vertical oscillation for NW was greater than that for FW at both speeds ($p = 0.025$ and $p = 0.001$, respectively; Figure 4A-B; Table 4), independent of the group.

2.3.1.4 Lateral oscillation

The lateral oscillation was affected by group at 1.8 $km.h^{-1}$ but not at 4.7 $km.h^{-1}$ (main effect: $p < 0.001$ and $p = 0.541$, respectively), and the same trend was observed for modality (main effect: $p < 0.001$ and $p = 0.740$, respectively). Moreover, a significant interaction was identified at both speeds (interaction effect: group x modality: $p < 0.001$ for both). Additionally, at both speeds, lateral oscillation for NW was lower in the Parkinson's group than in healthy controls ($p < 0.001$ and $p = 0.001$, respectively; Figure 1A-B; Table 4), and in the Parkinson's group, NW was lower than FW ($p < 0.001$ for both; Figure 1B; Table 4). In addition, FW in the Parkinson's group was greater than that in the healthy control group at 4.7 km.h^{-1} ($p < 0.001$; Figure 4A-B; Table 4). In healthy controls, NW was greater than FW at 4.7 km.h^{-1} ($p = 0.001$; Figure 4A; Table 4).

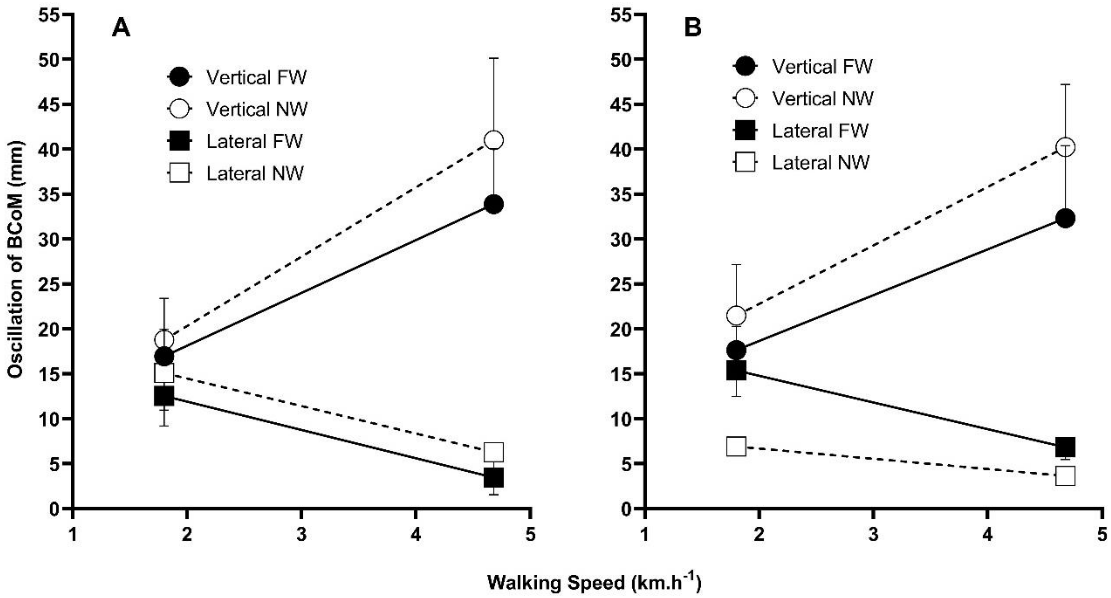

Figure 4 Lateral and vertical oscillation of body's center of mass (BCoM) as a function of speed; healthy control (A); Parkinson's group (B); continuous lines represent free walking (FW); interrupted lines represent Nordic walking (NW); vertical oscillation in FW (filled circles); vertical oscillation in NW (open circles); lateral oscillation in FW (filled square); lateral oscillation in NW (open square); for more information see Table 4.

2.3.1.5 Tau fractions - downward displacement

The downward displacement was not affected by group at 1.8 km.h^{-1} and 4.7 km.h^{-1} (main effect: $p = 0.079$ and $p = 0.096$, respectively), and it was affected by modality at 1.8 km.h^{-1} but not at 4.7 km.h^{-1} (main effect: $p = 0.005$ and $p = 0.898$, respectively). Moreover, a significant interaction was not identified at either speed (interaction effect: group × modality: $p = 0.109$ and $p = 0.651$, respectively). The downward displacement for NW was lower than that for FW at 1.8 km.h^{-1} ($p = 0.006$; Table 4), independent of the group.

2.3.1.6 Tau fractions - upward displacement

For both speeds of 1.8 km.h^{-1} and 4.7 km.h^{-1}, the upward displacement was not affected by group (main effect: $p = 0.848$ and $p = 0.200$, respectively) or by modality (main effect: $p = 0.368$ and $p = 0.893$, respectively). Moreover, a significant interaction was not identified at either speed (interaction effect: group × modality: $p = 0.714$ and $p = 0.462$, respectively; Table 4).

2.3.1.7 Single stance

For speeds of both 1.8 $km.h^{-1}$ and 4.7 $km.h^{-1}$, the single stance was affected by group ($p = 0.001$ and $p = 0.003$, respectively) and by modality ($p = 0.032$ and $p = 0.002$). Moreover, a significant interaction was not identified at either speed ($p = 0.144$ and $p = 0.619$, respectively). Additionally, for both speeds, the single stance for the Parkinson's group was lower than that for the healthy controls ($p = 0.001$ and $p = 0.003$, respectively), and the single stance for NW was greater than that for FW ($p = 0.032$ and $p = 0.002$, respectively). In the Parkinson's group, no difference was identified between the more and less affected side for FW ($p = 0.299$ and $p = 0.291$, respectively), and no difference was observed for NW at both speeds ($p = 0.323$ and $p = 0.473$, respectively; Table 4).

2.3.1.8 Double stance

For speeds of both 1.8 $km.h^{-1}$ and 4.7 $km.h^{-1}$, the double stance was affected by group ($p < 0.001$ and $p = 0.010$, respectively) and by modality ($p = 0.009$ and $p < 0.001$, respectively). Moreover, a significant interaction was not identified at either speed ($p = 0.243$ and $p = 0.239$, respectively). Additionally, for both speeds, the double stance for the Parkinson's group was lower than that for the healthy controls ($p < 0.001$ and $p = 0.011$, respectively) and the double stance for NW was greater than that for FW ($p = 0.010$ and $p < 0.001$, respectively; Table 4).

Table 4 Spatiotemporal parameters

Variables	Speed	Healthy control		Parkinson group		p-value		
		FW	NW	FW	NW	Group	Modality	Group* Modality
Vertical Oscillation (mm)	1.8 km.h^{-1}	17.0 ± 3.0	18.8±4.6	17.6±2.6	21.5±5.7	0.190	**0.024**	0.477
	4.7 km.h^{-1}	33.9±6.2	41.0 ± 9.1	32.3 ± 8.1	40.2 ± 7.0	0.619	**0.001**	0.866
Lateral Oscillation (mm)	1.8 km.h^{-1}	12.5 ± 3.3	15.1 ± 4.1	15.4 ± 2.9	6.9 ± 0.7 §†	**< 0.001**	0.238	**< 0.001**
	4.7 km.h^{-1}	3.5 ± 1.9	6.3 ± 2.9 ‡	6.8 ± 1.3 §	3.6 ± 0.9 §†	0.541	0.740	**< 0.001**
TUp (s)	1.8 km.h^{-1}	0.48 ± 0.03	0.49 ± 0.02	0.48 ± 0.02	0.49 ± 0.02	0.848	0.368	0.714
	4.7 km.h^{-1}	0.52 ± 0.02	0.52 ± 0.01	0.51 ± 0.02	0.51 ± .0.01	0.200	0.893	0.462
TDown (s)	1.8 km.h^{-1}	0.52 ± 0.01	0.49 ± 0.01	0.52 ± 0.01	0.51 ± 0.01	0.079	**0.005**	0.109
	4.7 km.h^{-1}	0.48 ± 0.03	0.48 ± 0.01	0.49 ± 0.01	0.49 ± 0.01	0.096	0.898	0.651
Step Frequency (Hz)	1.8 km.h^{-1}	1.26 ± 0.06	1.21 ± 0.10 ‡	1.38 ± 0.14	1.36 ± 0.19 §	**< 0.001**	**< 0.001**	**< 0.001**
	4.7 km.h^{-1}	1.92 ± 0.13	1.93 ± 0.18	2.15 ± 0.17	2.14 ± 0.16	**< 0.001**	0.923	0.780
Step Length (m)	1.8 km.h^{-1}	0.38 ± 0.02	0.40 ± 0.03 ‡	0.35 ± 0.03 §	0.37 ± 0.03 §	**< 0.001**	**< 0.001**	**< 0.001**
	4.7 km.h^{-1}	0.66 ± 0.07	0.66 ± 0.06	0.59 ± 0.05	0.60 ± 0.05	**< 0.001**	0.823	0.795
Single Stance (s)	1.8 km.h^{-1}	1.07 ± 0.11	1.21 ± 0.15	0.99 ± 0.12	1.01 ± 0.14	**0.001**	**0.032**	0.114
	4.7 km.h^{-1}	0.62 ± 0.07	0.69 ± 0.09	0.57 ± 0.06	0.62 ± 0.04	**0.003**	**0.002**	0.619
Double Stance (s)	1.8 km.h^{-1}	0.28 ± 0.04	0.35 ± 0.08	0.24 ± 0.05	0.26 ± 0.05	**< 0.001**	**0.009**	0.243
	4.7 km.h^{-1}	0.12 ± 0.01	0.18 ± 0.07	0.10 ± 0.02	0.14 ± 0.04	**0.010**	**< 0.001**	0.239

Values are presented by means and standard deviation. Tau fraction upward displacement (T Up); Tau fraction downward displacement (T Down); free walking (FW); nordic walking (NW). Superscript symbols indicate statistically significant differences (p <0.01 and p 0.05) within-effect (with versus without poles) in Parkinson group (†), Healthy Control (‡), between-effect (Parkinson versus Healthy control) in FW and NW conditions (§).

2.3.2 Mechanical paraments

2.3.2.1 Internal mechanical work

For speeds of both 1.8 $km.h^{-1}$ and 4.7 $km.h^{-1}$, the internal mechanical work was affected by group (main effect: $p = 0.003$ and $p < 0.001$, respectively) but not by modality (main effect: $p = 0.446$ and $p = 0.728$, respectively). Moreover, a significant interaction was not identified at either speed (interaction effect: group × modality: $p = 0.672$ and $p = 0.760$, respectively). The internal mechanical work for the Parkinson's group was greater than healthy controls at both speeds ($p = 0.003$ and $p < 0.001$, respectively; Figure 5A-B; Table 5), independent of the modality.

2.3.2.2 External mechanical work

The external mechanical work was not affected by group at 1.8 $km.h^{-1}$ and 4.7 $km.h^{-1}$ (main effect: $p = 0.086$ and $p = 0.919$, respectively), nor by modality at 1.8 $km.h^{-1}$ (main effect: $p = 0.797$), but it was affected by modality at 4.7 $km.h^{-1}$ (main effect: $p < 0.001$). Moreover, a significant interaction was not identified at 1.8 $km.h^{-1}$ but was identified at 4.7 $km.h^{-1}$ (interaction effect: group × modality: $p = 0.696$ and $p = 0.016$, respectively). In the Parkinson's group, external mechanical work for NW was greater than FW at 4.7 $km.h^{-1}$ ($p < 0.001$; Figure 5B; Table 5).

2.3.2.3 Total mechanical work

The total mechanical work was affected by group at 1.8 $km.h^{-1}$ and 4.7 $km.h^{-1}$ (main effect: $p = 0.017$ and $p = 0.018$, respectively), and it was not affected by modality at 1.8 $km.h^{-1}$ (main effect: $p = 0.910$), but it was affected at 4.7 $km.h^{-1}$ (main effect: $p = 0.001$). Moreover, a significant interaction was not identified at either speed (interaction effect: group x modality: $p = 0.626$ and $p = 0.054$, respectively). The total mechanical work in the Parkinson's group was greater in comparison to healthy controls at both speeds ($p = 0.017$ and $p = 0.018$, respectively; Figure 5A-B; Table 5), independent of modality. In addition, NW was greater than FW at 4.7 $km.h^{-1}$ ($p = 0.001$; Figure 5A-B; Table 5).

2.3.2.4 Forward mechanical work

For both speeds of 1.8 $km.h^{-1}$ and 4.7 $km.h^{-1}$, the forward mechanical work was not affected by group (main effect: $p = 0.103$ and $p = 0.973$, respectively) or by modality (main effect: $p = 0.215$ and $p = 0.235$, respectively). Moreover, a significant interaction was identified at 1.8 $km.h^{-1}$ but not at 4.7 $km.h^{-1}$ (interaction effect: group × modality: $p = 0.008$ and $p = 0.082$, respectively). In the Parkinson's group, forward mechanical work for NW was greater than FW at 1.8 $km.h^{-1}$ ($p = 0.024$; Figure 5D; Table 5). In addition, FW was lower in the Parkinson's group than in the healthy control group ($p = 0.018$; Figure 5C-D; Table 5).

2.3.2.5 Vertical mechanical work

The vertical mechanical work was affected by group at 1.8 $km.h^{-1}$ and 4.7 $km.h^{-1}$ (main effect: $p = 0.014$ and $p = 0.019$, respectively), and it was not affected by modality at 1.8 $km.h^{-1}$ (main effect: $p = 0.837$), but it was affected at 4.7 $km.h^{-1}$ (main effect: $p = 0.001$). Moreover, a significant interaction was not identified at either speed (interaction effect: group x modality: $p = 0.255$ and $p = 0.413$, respectively). The vertical mechanical work in the Parkinson's group was greater in comparison to healthy controls at both speeds ($p = 0.014$ and $p = 0.019$, respectively; Figure 5C-D; Table 5), independent of modality. In addition, NW was greater than FW at 4.7 $km.h^{-1}$ ($p = 0.001$; Figure 5C-D; Table 5).

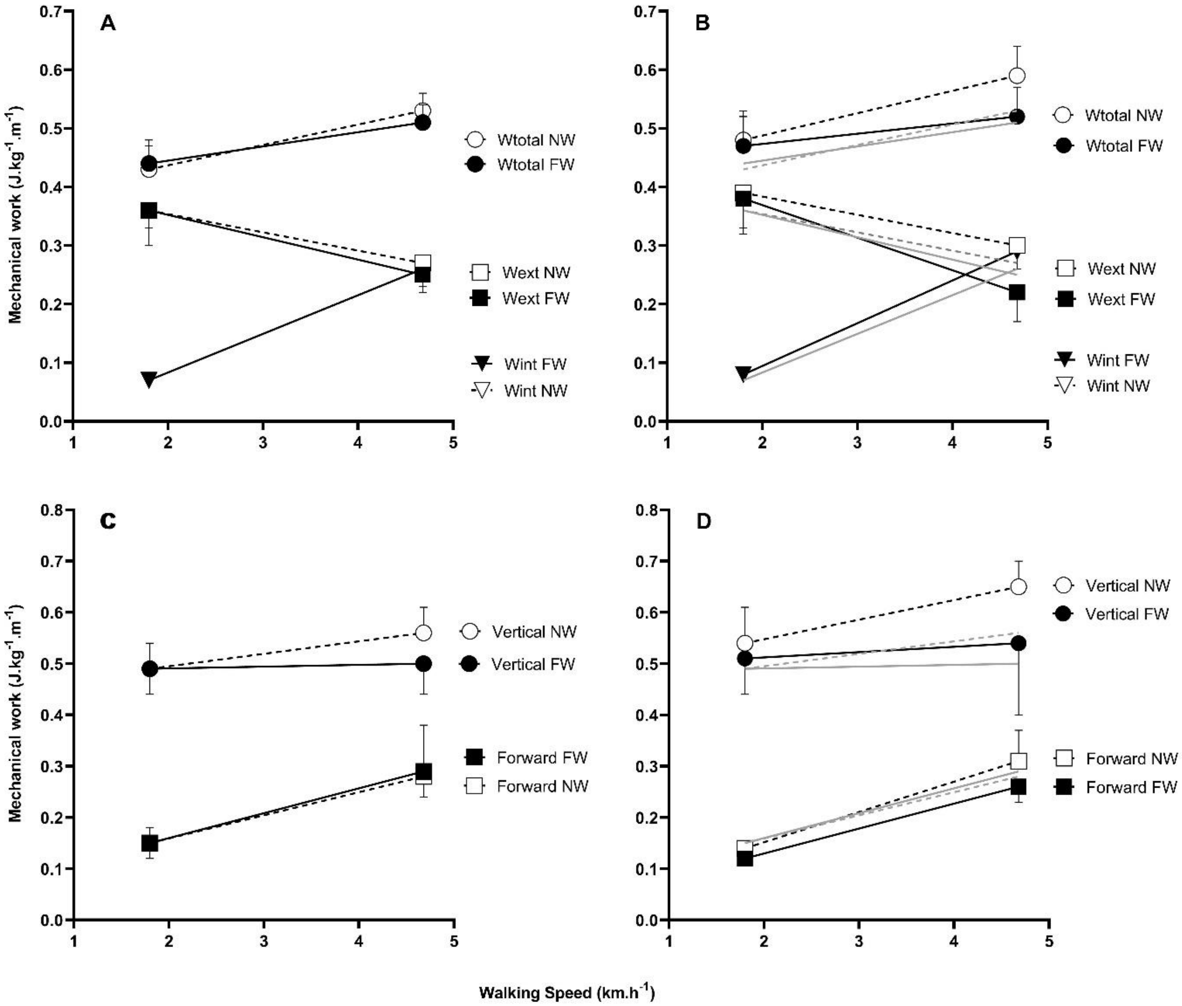

Figure 5 Mechanical parameters as a function of speed; healthy controls (A and C); Parkinson's group (B and D); continuous lines represent free walking (FW); interrupted lines represent Nordic walking (NW); total mechanical work (W_{tot}); external mechanical work (W_{ext}); internal mechanical work (W_{int}); W_{tot} in FW (filled circles); W_{tot} in NW (open circles); W_{ext} in FW (filled square); W_{ext} in NW (open square); W_{int} in FW (filled triangle); W_{int} in NW (open triangle); vertical mechanical work in FW (filled circles); vertical mechanical work in NW (open circles); forward mechanical work in FW (filled square); forward mechanical work in NW (open square); healthy control behavior plotted in Parkinson's group (gray line); for more information see Table 5.

2.3.3 Pendulum-Like parameters

2.3.3.1 Recovery

For speeds of both 1.8 km.h^{-1} and 4.7 km.h^{-1}, the recovery was not affected by group (main effect: $p = 0.729$ and $p = 0.648$, respectively), but it was affected by modality (main effect: $p = 0.001$ and $p < 0.001$, respectively). Moreover, for both speeds, a significant interaction was identified (interaction effect: group × modality: $p = 0.006$ and $p < 0.001$, respectively), and in the Parkinson's group, recovery for NW was greater than that for FW ($p < 0.001$ for both speeds). In addition, recovery for FW in the Parkinson's group was lower than that in the healthy control group at 4.7 km.h^{-1} ($p = 0.010$; Table 5).

Table 5 Mechanical and pendulum-Like parameters

Variables	Speed	**Healthy control**		**Parkinson group**		**p-value**		
		FW	NW	FW	NW	Group	Modality	Group* Modality
W_{ext} (J.kg^{-1}.m^{-1})	1.8km.h^{-1}	0.36 ± 0.03	0.36 ± 0.06	0.38 ± 0.06	0.39 ± 0.06	0.086	0.797	0.696
	4.7km.h^{-1}	0.25 ± 0.03	0.27 ± 0.02	0.22 ± 0.05	0.30 ± 0.04 †	0.919	**< 0.001**	**0.016**
W_f (J.kg^{-1}.m^{-1})	1.8km.h^{-1}	0.15 ± 0.03	0.15 ± 0.03	0.12 ± 0.01 §	0.14 ± 0.01 †	0.103	0.215	**0.008**
	4.7km.h^{-1}	0.29 ± 0.09	0.28 ± 0.04	0.25 ± 0.03	0.31 ± 0.06	0.973	0.235	0.082
W_v (J.kg^{-1}.m^{-1})	1.8km.h^{-1}	0.49 ± 0.05	0.49 ± 0.05	0.51 ± 0.07	0.54 ± 0.07	**0.014**	0.837	0.255
	4.7km.h^{-1}	0.50 ± 0.06	0.56 ± 0.05	0.53 ± 0.14	0.65 ± 0.05	**0.019**	**0.001**	0.413
W_{int} (J.kg^{-1}.m^{-1})	1.8km.h^{-1}	0.07± 0.00	0.07 ± 0.01	0.08 ± 0.01	0.08 ± 0.01	**0.003**	0.446	0.672
	4.7km.h^{-1}	0.26 ± 0.02	0.26 ± 0.03	0.29 ± 0.03	0.29 ± 0.03	**< 0.001**	0.728	0.760
W_{tot} (J.kg^{-1}.m^{-1})	1.8km.h^{-1}	0.44 ± 0.03	0.43 ± 0.05	0.47 ± 0.05	0.48 ± 0.05	**0.017**	0.910	0.626
	4.7km.h^{-1}	0.51 ± 0.03	0.53 ± 0.03	0.52 ± 0.05	0.59 ± 0.05	**0.018**	**0.001**	0.054
R (%)	1.8km.h^{-1}	39.9 ± 3.1	40.3 ± 1.5	38.3 ± 1.9	42.5 ± 2.5 †	0.729	**0.001**	**0.006**
	4.7km.h^{-1}	66.5 ± 1	66.9 ± 2	62.7 ± 2.7 §	70.1 ± 4.6 †	0.648	**< 0.001**	**< 0.001**

Values are presented by means and standard deviation. External mechanical work (W_{ext}); forward mechanical work (W_f); vertical mechanical work (W_v); internal mechanical work (W_{int}); total mechanical work (W_{tot}); recovery(R); free walking (FW); Nordic walking (NW). Superscript symbols indicate statistically significant differences (p <0.01 and p 0.05) within-effect (with versus without poles) in Parkinson group (†), Healthy Control (‡), between-effect (Parkinson versus Healthy control) in FW and NW conditions (§).

2.4 Discussion

This study compared the mechanical, pendulum-like, and spatiotemporal parameters of gait at different speeds with and without NW poles in people with PD and healthy controls. Based on comparisons of published data and with the adoption of a more complete work production analysis, our hypothesis was partially confirmed. This study showed that the pendulum-like energy recovery was increased in the Parkinson’s group during NW compared to FW, while external mechanical work remained similar. The Parkinson’s group also demonstrated reduced stride length and increased stride frequency in comparison to healthy controls with or without the poles. Collectively, our study indicated that the greater metabolic cost of Parkinson's in FW (NARDELLO et al., 2017) is, at least partially, explained by the higher total mechanical work and impaired pendulum-like energy recovery due to the slow speed commonly used by the people with PD.

The work done at each step during walking to lift the body’s center of mass (vertical mechanical work), to increase its forward speed (forward mechanical work) and mechanical kinetic and potential energy (external mechanical work), and to accelerate the limbs relative to the body’s center of mass (internal mechanical work) were measured (Table 5). The external mechanical work in the Parkinson's group remained similar in FW compared to the healthy control group. This can be explained mainly by the unchanged pendulum-like energy recovery, which in turn is dependent on kinetic and potential energy fluctuations, in line with previous findings (DIPAOLA et al., 2016). In addition, the external mechanical work components remained unchanged, except the lower forward mechanical work at 4.7 $km.h^{-1}$. We speculate that this is due to the low activity of the medial gastrocnemius, as it is important for the forward propulsion in the terminal phase of stance (ISLAM et al., 2020). However, these changes were not sufficient to increase pendulum-like energy recovery at 4.7 $km.h^{-1}$. Moreover, the internal work in the Parkinson's group was higher than that in the healthy control group, which was mainly responsible for the increased total mechanical work. This finding supports what has been previously hypothesized, explaining the higher energy expenditure in the gait of Parkinson’s people compared to healthy controls(NARDELLO et al., 2017) (Figure 6).

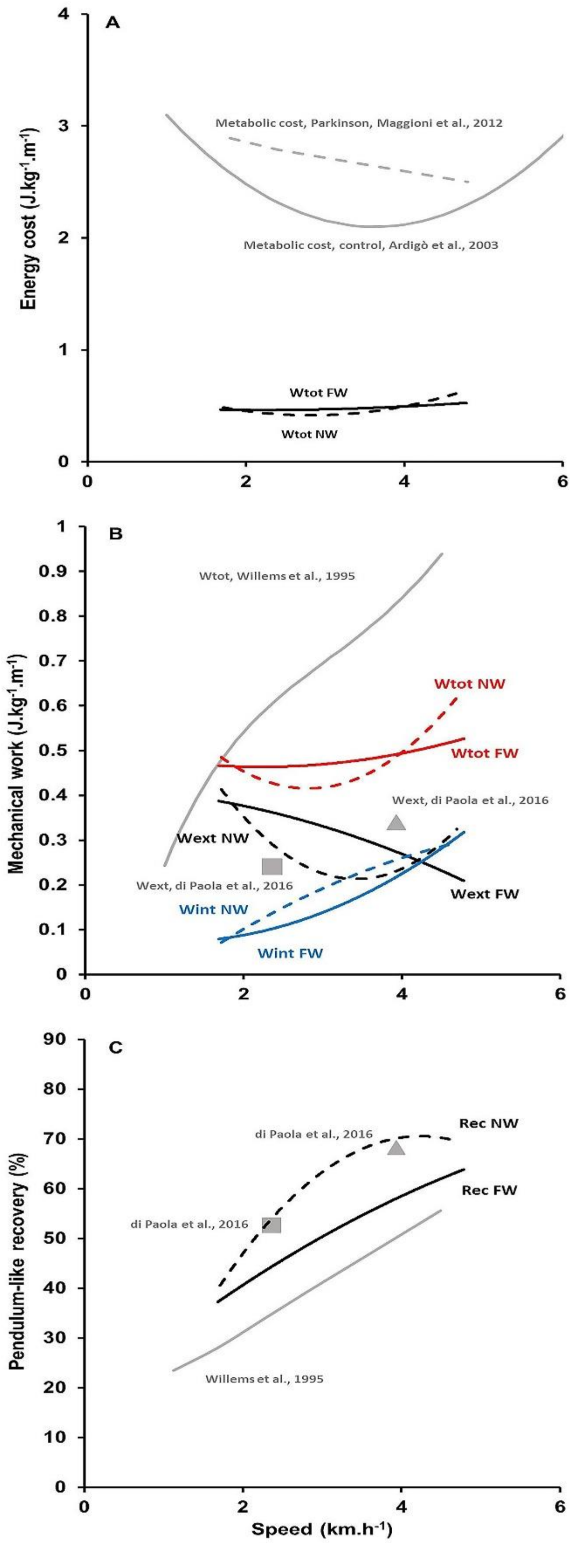

Figure 6 Energy cost (A); mechanical work (B) and pendulum-like recovery (C) parameters as a function of speed; Parkinson's group and healthy controls in free walking (FW) with superposed (gray line) of data from the literature for comparison**;** continuous lines represent FW; interrupted lines represent Nordic walking (NW). The black line indicates total mechanical work (A); the red line indicates total mechanical work (B); the black line indicates external mechanical work; the blue line indicates internal mechanical work (B); the black line indicates pendulum-like recovery (C).

When walking with poles, the external mechanical work during NW in comparison to FW at 1.8 km.h^{-1} remained unchanged in the Parkinson’s group, which was in agreement with NW instructors (PELLEGRINI et al., 2017), but it increased at 4.7 km.h^{-1}. We believe that high speed is a more challenging condition, notably because it is very distinct from the self-selected walking speed of this population (ZANARDI et al., 2021). In general, at 1.8 km.h^{-1}, the external work did not change because there was compensation regarding greater variations in the forward and vertical energies, which in turn produced a high recovery. This similar response occurs at 4.7 km.h^{-1}, but it is not sufficient to remained similar the external mechanical work. Therefore, contrary to healthy people, where the greater total work using poles is due to internal work from the arms, PD people generate higher total work due to external work. In addition, this can be the main factor for increased energy expenditure during NW in people with PD (NARDELLO et al., 2017).

The temporal symmetry of the body’s center of mass displacement is a determinant for the optimization of inverted pendulum-like and is evaluated by observing the upward and downward displacements (Table 4). In healthy males during FW, the upward and downward displacements are symmetrical at their self-selected walking speed (~ 5.76 km.h^{-1}) reaching greater recovery energy, and the times become asymmetrical in speeds below 3.24 km.h^{-1} and above 6.84 km.h^{-1} (CAVAGNA; LEGRAMANDI, 2020). With respect to NW, the times were approximately equal in the Parkinson’s group with trends of symmetry only at 1.8 km.h^{-1}. This is in line with a previous study that reported similar times in healthy males during FW at the most common speed (CAVAGNA; LEGRAMANDI, 2020), resulting in a higher pendulum-like recovery during NW than in FW.

For spatiotemporal parameters of gait, in a healthy people, the step frequency is related to the work done in each step to accelerate the limbs relative to the body’s center of mass (internal mechanical work), and the step length is related to the work done in each step to lift and accelerate the center of mass relative to the environment (external mechanical work) (CAVAGNA; THYS; ZAMBONI, 1976; MINETTI; CAPPELLI; ZAMPARO, 1995). In FW, the step frequency was higher in the Parkinson's group than in the healthy controls, in agreement with a previous study (DIPAOLA et al., 2016; ZANARDI et al., 2021), and thus it depends on the reduced single and double stance time, which in turn affected the increased internal mechanical work (CAVAGNA; THYS; ZAMBONI, 1976; MINETTI; CAPPELLI; ZAMPARO, 1995) in the present study. In addition, the step length was shorter in the Parkinson's group, similar to those reported in previous studies (DIPAOLA et al., 2016; ZANARDI et al., 2021), but it did not change the external mechanical work.

Surprisingly, the Parkinson’s group using NW poles showed higher step frequency in comparison to healthy controls at 1.8 km.h^{-1}, and thus it depends on reduced single and double stance time, but it was not sufficient to change the internal mechanical work. In line with this, the stride length was lower in the Parkinson’s group than in the healthy controls during NW at 1.8 km.h^{-1}, which in turn, was not able to change the external mechanical work. These changes suggest that PD people demonstrate distinct adjustments in spatiotemporal parameters compared to NW instructors when walking with poles (PELLEGRINI et al., 2017). We believe this is possibly because people with PD have a modified NW technique caused by restrictions of motor symptoms due to the disease, such as bradykinesia and rigidity (ZESIEWICZ, 2019). It is likely that people with PD apply one technique that is more stabilizing than propulsive altering of the muscle patterns and reducing the differences in spatiotemporal parameters (PELLEGRINI et al., 2018). These symptoms produce large asymmetry between the lower and upper limbs, reduced range of motion, high co-contractions (ZANARDI et al., 2021), and worsened motor patterns by dual-task performance (WILD et al., 2013). This response may explain the disagreement between spatiotemporal gait parameters in healthy people in comparison to people with PD in the NW condition.

The self-selected walking speed of the Parkinson's group in FW was lower than that of healthy controls, in line with the literature (ZANARDI et al., 2021). The primary reason for the lower speed is a decrease in stride length (YANG et al., 2008). However, the use of poles did not change the self-selected walking speed in the Parkinson's group acutely, contrasting with the findings of NW instructors (PELLEGRINI et al., 2017). However, this analysis was performed on a motorized treadmill, and changes in gait parameters were expected when compared to ground assessments (CAVAGNA; HEGLUND; TAYLOR, 1977; ZANARDI et al., 2021). Furthermore, in treadmill conditions, the step length-frequency relationship in people with PD is increased when compared to overground conditions (ZANARDI et al., 2021). Indeed, more ecological walking conditions appear to be more accurate in showing spatiotemporal parameters. Despite this, studies suggest that walking interventions with poles increase the self-selected walking speed as a chronic adaptation in people with PD (BOMBIERI et al., 2017) and older people (GOMEÑUKA et al., 2019). In addition, walking speed is currently a considerable predictor of mobility, functionality, and mortality (PETERSON et al., 2020).

For the oscillation of the body's center of mass during walking, we found a larger lateral oscillations in the Parkinson's group than in healthy controls in FW at 4.7 $km.h^{-1}$, probably due to reduced lateral pelvic displacement in the gait of PD people (BANASZKIEWICZ; KADER, 2014). However, NW increased vertical oscillations in the Parkinson's and healthy control groups and decreased lateral oscillations only in the Parkinson's group in NW compared to FW. This means that walking with NW poles is a safe activity and seems to be used in the studied group mainly as a stabilizing target rather than for forward propulsion.

The present study had some limitations. We only recruited people with PD in stages between 1 and 1.5 (1±0.5) based on the H&Y scale, which represents mild to moderate levels of gait restriction. In our study, the internal mechanical work was not computed by the center of the segmental mass, as estimated by the equation previously proposed (CAVAGNA; LEGRAMANDI; PEYRÉ-TARTARUGA, 2008).

2.5 Conclusion

Finally, our findings aid in the discussion of rehabilitation based on gait parameters and mechanical energies using NW poles. This study demonstrated that the use of NW poles increased the pendulum-like energy recovery of people with PD, without changes in external mechanical work. We observed that PD people demonstrate some specific gait adjustments that are contrary to those observed in healthy controls; this is due to restrictions caused by the symptoms of the disease. This study also indicated that external mechanical work did not change, as reported in previous literature (DIPAOLA et al., 2016). Here, in a more complete analysis of the generation of total mechanical work, we noticed that the internal mechanical work in the gait of PD people is responsible for the higher energy expenditure during FW. In line with this, NW seems to be a safe and accessible activity, specifically increasing pendulum-like recovery as well as external mechanical work at fast speeds for people with PD.

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Conflict of Interest

There are no conflicts of interest in this study.

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CHAPTER 3

LOCOMOTION WITH POLES: KINETIC RESPONSES IN FAST WALKING AND RUNNING IN PARKINSON'S DISEASE.

Abstract

Background: While changes in ground reaction force (GRF) components are observed during walking in people with Parkinson's disease (PD), these responses using poles during walking and running are unknown. **Methods:** This study compared the kinetic and spatiotemporal parameters at fast walking speed and running with and without poles in PD and healthy people. The study included eleven people (Age 65.6 ± 7.0) with the clinical diagnosis of idiopathic PD and staging between 1 and 2 in the Hoehn and Yahr scale (H&Y) and nine healthy people (Age 70.0 ± 5.6). **Results:** We found greater vertical (terminal stance) and anteroposterior (braking and propulsive) GRF maximal values ($p<0.05$) in the Parkinson group during Nordic walking in comparison to free walking. During Nordic running, people with PD decreased the vertical components of the GRF ($p<0.05$) in comparison to free running and the anteroposterior maximal GRF values resulted similar ($p>0.05$) to the healthy controls. The Nordic walking and running reduced step frequency ($p>0.05$) similarly in both groups. Our results suggest Nordic walking and running modify gait patterns and lead to compensatory adjustments to reduce motor symptoms of PD. The use of poles during walking and running appears to be a functional and safe activity.

Keywords: Parkinsonism; gait; sticks; ground reaction force

3.1 Introduction

Parkinson’s disease (PD) is a progressive, age-related, neurodegenerative disease associated with dopamine deficiency (SIMON; TANNER; BRUNDIN, 2020), which impacts locomotion, decreases the gait speed, step length and frequency, muscle activation, and increased gait variability and energy expenditure (ZANARDI et al., 2021). These factors are associated with an increased risk of falls and reduced activities of daily living and quality of life (ZANARDI et al., 2021).

For walking at higher speeds, however, the biomechanical alterations are less known in PD. Even the PD is restrictive in terms of gait speed, recent evidence has supported the notion that faster speed walking may be a promising locomotor rehabilitation strategy (BALBINOT et al., 2020). People with PD tend to benefit from exercise programs targeting increased gait speed. Nevertheless, the insights on faster walking speed still need to be better investigated, as well as studies evaluating the effects of running in people with PD are still scarce. Running condition, while challenging, seems to have been feasible and safe (PASSOS-MONTEIRO et al., 2020). Understanding the relationships between gait and speed is extremely important to determine effective interventions for people with PD.

From the metabolic point-of-view, the high-intensity multimodal (KELLY et al., 2017; LANDERS et al., 2019), sprint (PASSOS-MONTEIRO et al., 2020), and stationary bicycle (FIORELLI et al., 2019; JANSEN et al., 2021) exercise programs are feasible and safe in PD. High-Intensity exercise may have beneficial effects on PD, increasing the activity on substantia nigra and prefrontal brain areas (KELLY et al., 2017) and improving cardiorespiratory fitness, balance, walking performance, motor symptoms, and quality of life. Furthermore, fast walking speed and running have been used previously in Nordic walking (NW) training programs for intensity modulation in PD (FRANZONI et al., 2018; ZANARDI et al., 2019) with functional improvement. However, the method of running with poles should be better understood to be incorporated into training. However, the evidence is yet limited.

Additionally, different poles techniques seem to change the responses of the ground reaction force (GRF) of the second half stance (WILLSON et al., 2001). Therefore, the GRF components responses could aid in understanding the effects of the NW poles on motor symptoms, propulsion and stabilization adjustments during PD locomotion, and certifying the safety of using poles at high speed. However, the acute effect of the use of poles on the parameters of GRF and spatiotemporal during fast walking speed and running in people with PD is still unknown. Therefore, this study compared the kinetic and spatiotemporal parameters walking (at fast speed) and running with and without NW poles in people with PD and age-matched control group. We hypothesized that in the first half stance, the vertical and the anteroposterior components of the GRF would increase and in the second half would decrease during fast walking speed and running with the use of the poles in the Parkinson group.

3.2 Methods

3.2.1 Subjects and ethics statement

The study was conducted with eleven volunteers with PD (6 male and 5 female; (mean ± standard deviation) age = 65.6 ± 7.0 years; height = 1.63 ± 0.11 m; weight = 71.1 ± 14.8 kg; body mass index = 26.5 ± 3.5; lower limb length = 0.87 ± 0.05; disease durations = 9.4 ± 7.2 years; Unified Parkinson's Disease Rating Scale motor part - III = 11.6 ± 3.4; Hoehn & Yahr scale = 1 ± 0.5 (median ± interquartile range)) and nine healthy control (5 male and 4 female; age = 70 ± 5.6 years; height = 1.69 ± 0.1 m; weight = 73 ± 10 kg; body mass index = 25.6 ± 3.4; lower limb length = 0.87 ± 0.1). No statistically significant differences were found between groups for other anthropometric characteristics.

The present investigation was an observational study with non-probability sampling. All participants were aware of the conditions and procedures of the study before signing their consent to participate. The local ethics committee approved this study (n° 69919017.3.0000.5347). The inclusion criteria were: 1) people of both sexes aged over 50 years, experienced Nordic Walkers with at least six months of experience in the modality and stage of PD between 1 and 1.5 on the modified H&Y scale; 2) the capability to walk independently on the walkway with and without poles; 3) been in the "ON" period of drug treatment, no later than three hours after ingestion drugs occurred at least one hour before the protocol test. The healthy people also took apart this study with the same eligibility criteria (except H&Y scale). The exclusion criteria for both groups were: a history of respiratory and cardiovascular diseases, musculoskeletal injuries, underwent surgeries, labyrinthitis in the last year, prosthesis users of both upper or lower limbs, unable to understand verbal commands, and to perform the tests protocol.

3.2.2 Study design

The gait protocol consisted of three different days with a minimum interval of 48 hours and a maximum of 72 hours between days. On the first day was conducted an assessment of the individual sample characteristics. On the second day, we randomized the walking modality (free walking (FW) and NW) and gait type (fast walking and running) by software Randomizer (randomizer.com). After that, a familiarization of walking on a walkway was executed by five minutes, followed by the walking and running trials for data collection.

3.2.3 Data acquisition of ground reaction forces

The GRF components vertical (GRF-V), anteroposterior (GRF-AP) were recorded by a three-dimensional measurement system setup on a walkway (1.2 m wide x 6 m long) with eight built-in force platforms (INFINIT-T, BTS, Bioengineering, Italy) (figure 1), with a sampling rate of 1000 Hz. The data collection was managed by SMART Capture software (BTS, Bioengineering, Italy). The static calibration was performed before walking and running tests, with the subject in orthostatic position on a reference platform where the bodyweight record (Figure 7).

The subject was evaluated with NW poles (NW and Nordic running (NR)) without NW poles (FW and free running) at self-selected running and fast walking speed. The poles length was determined by the International NW Federation (subject’s height * 0.65), (NARDELLO et al., 2017). For the NW condition, all people were asked to use the diagonal technique recommended by the International NW Federation (PELLEGRINI et al., 2015). For the NR condition, the people were asked to use the NR diagonal technique, characterized by the support of the poles continued during the swing phase (KŮTEK; TVRZNÍK, 2014).

Five trials were performed over the walkaway in both gaits (walking and running) and modalities (NW and FW) (SHARIFMORADI; FARAHPOUR, 2016). People were asked to return to the initial position in walkaway at the end of each trial to continue a new test. One minute of rest was adopted between trials and five minutes between the speeds (PASSOS-MONTEIRO et al., 2020). All speed conditions were controlled by a digital chronometer when subject across markers positioned before and after the force platforms. Verbal commands were used to explain the speed during the trials: for walking, “now you should walk as fast as possible without running,” for running, “now you should run at your comfortable speed.” Similarly, the verbal command reminds the people to maintain the better technique during the use of poles: “good job, remember to maintain the correct technique!”. The recorded walking speed of each trial was later verified during GRF data analysis.

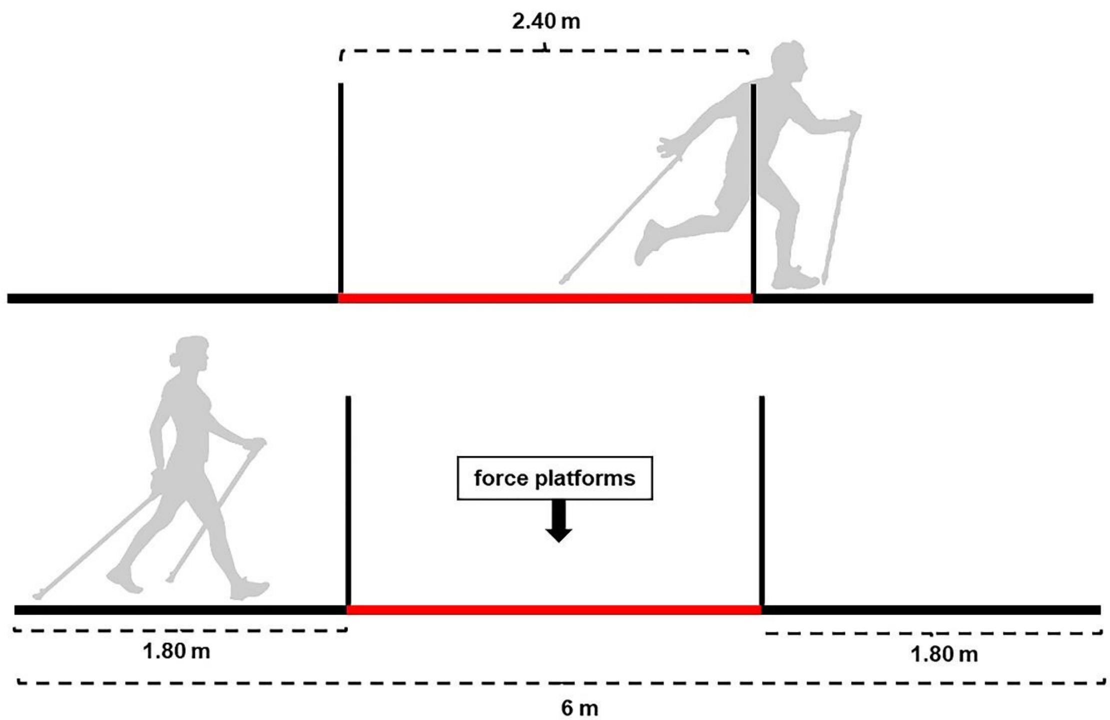

Figure 7 Experimental set-up of the gait test protocol, the above part of the image represents the Nordic running and the below part represents the Nordic walking.

3.2.4 Kinetic parameters

A mathematical routine in MATLAB (2012b, MathWorks Inc., Natick, Massachusetts, USA) was used to analyze the GRF-V and GRF-AP raw data of individual steps. The data were normalized by body weight and then identified (HEIDNER et al., 2020) (Figure 8).

We defined the gait step starting at the heel ground contact and ending at the next ground contact of the contralateral heel. The steps were divided according to the maximum forward velocity (DEWOLF et al., 2017). The step was considered valid for analysis only when the subject was walking at a relatively constant mean speed. Thus, the sum of the increments of the vertical velocity and the forward velocity of the body center of mass could not be more significant than 25% of the decrements (CAVAGNA, 1975; SCHEPENS et al., 2004). One trial per subject and modality was analyzed, yielding 100 sets in walking (20 people x 2 modality x 5 trials) and 100 sets in the running (20 people x 2 modality x 5 trials). Moreover, a total of 201 steps were analyzed.

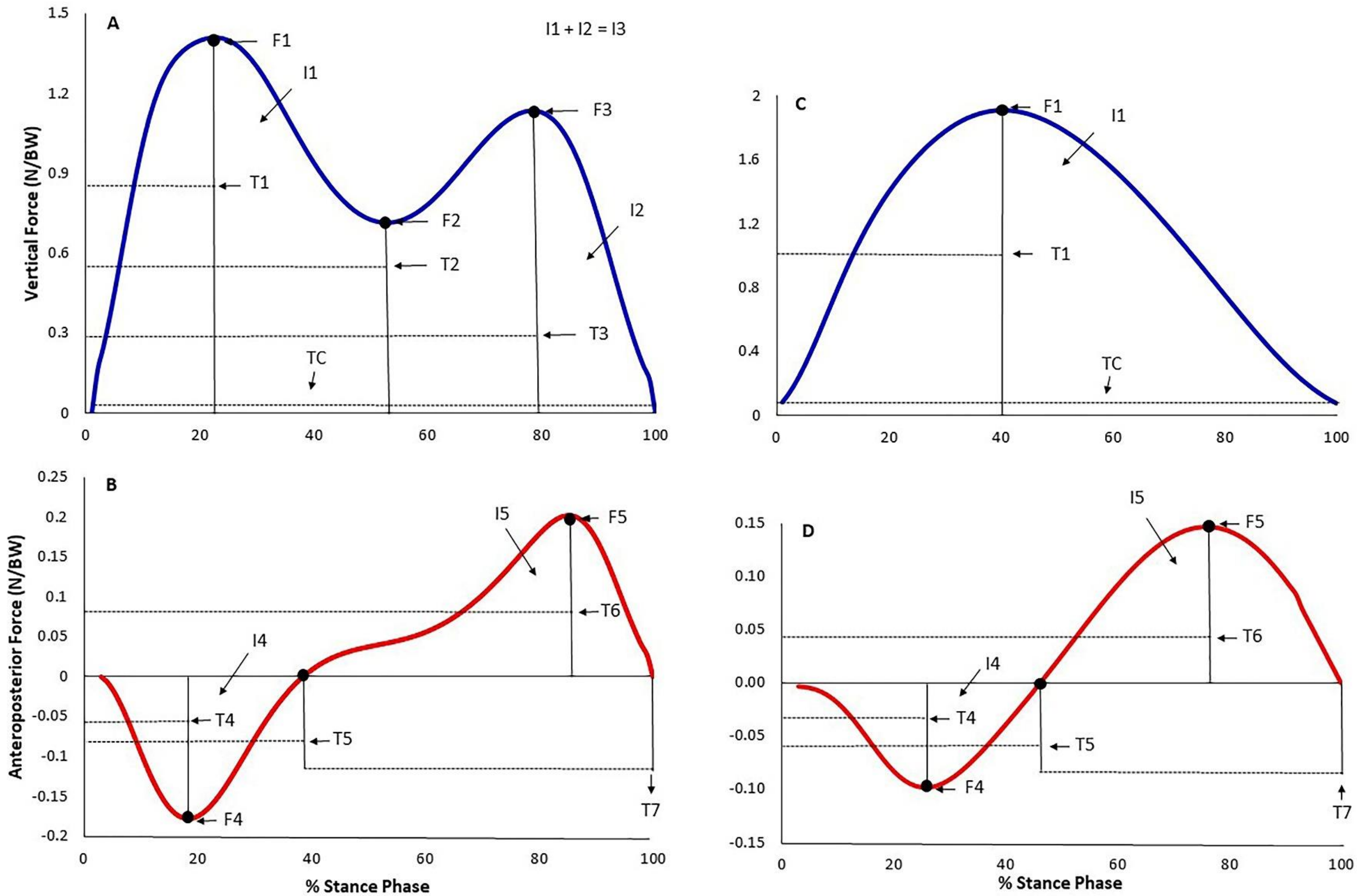

Figure 8 Vertical and anteroposterior ground reaction force during fast walking speed (A and B) and running (C and D) from Parkinson group as a function of percentual of stance phase. Loading response peak force (F1), midstance force (F2), terminal stance peak force (F3), braking peak force (F4), propulsive peak force (F5). After that, was determined the times related to the force events, time to loading response peak force (T1), time to midstance force (T2), time to terminal stance peak force (T3), time to braking peak force (T4), duration of braking phase (T5), time to propulsive peak force (T6), duration of propulsive phase (T7). Also, the area under the curve was calculated to measure the loading response impulse (I1), terminal stance impulse (I2), braking impulse (I4), propulsive impulse (I5), the total vertical impulse (I3) was obtained by the sum of I1 and I3 (HEIDNER et al., 2020).

3.2.5 Spatiotemporal parameters

The forward velocity (V_f) of the center of body mass was determined by the GRF-AP (CAVAGNA, 1975). The step length was obtained from the multiplication of V_f by the period of the step (T) ($SL = V_f \cdot T$) (CAVAGNA; FRANZETTI; FUCHIMOTO, 1983). The step frequency was obtained by the inverse of step period ($SF=1/T$) (CAVAGNA; FRANZETTI; HEGLUND, 1988). Finally, the single stance was calculated as the fraction of the period during which one foot only contacts the ground (CAVAGNA; FRANZETTI; FUCHIMOTO, 1983). All data were processed using Excel 2016 (Microsoft Corporation, Redmond, Washington, USA) and Matlab 9.4 (MathWorks Inc., Natick, MA, USA) with a fourth-order low-pass Butterworth filter, a cut-off frequency of 10 Hz.

3.2.6 Statistical analysis

All data are presented as means and standard deviations. The sample characteristics data were compared through an Independent-Sample T-Test. The symmetry index between the more and less affected side in the Parkinson group (ZANARDI et al., 2019) was evaluated using the Paired-Samples T-test. No difference between the more and less affected sides was observed when only one side was chosen. The Generalized Linear Model (GLZM) was used for identifying the main effects group (control x Parkinson group), modality (with x without poles), and group x modality interactions, and Bonferroni post hoc was used to find the statistical differences. We tested the gamma and linear distribution models and chose the model best fitted to the data, defined by the lowest Akaike's Information Criterion (AIC) value. The statistical analysis was performed by software Statistical Package for Social Sciences (SPSS, Chicago, USA) v.26. The significance level was $\alpha = 0.05$.

3.3 Results

3.3.1 Fast walking speed

3.3.1.1 Kinetic parameters

The vertical and anteroposterior curves of the NW and FW from the Parkinson group are shown in Figure 9. The midstance force was affected by group ($p = 0.007$) but was not affected by modality ($p = 0.087$), and significative interaction of group*modality was not identified ($p = 0.160$). The Parkinson group was greater than the healthy control ($p = 0.007$; Table 6), modality-independent. The loading response peak force, terminal stance peak force, braking force, propulsive peak force were not affected by group or modality, and significative interactions were not identified (Table 6).

The time to terminal peak force was not affected by group ($p = 0.256$) and modality ($p = 0.064$). Moreover, a significative interaction group*modality was identified ($p = 0.003$). The time to terminal peak force during NW in the Parkinson group was longer than in the healthy control ($p = 0.021$). In Parkinson group, NW was longer than FW ($p = 0.002$; Table 6).

The time of braking phase was affected by group ($p = 0.002$) and modality ($p = 0.038$). Moreover, a significative interaction group*modality was identified ($p = 0.009$). The time of braking phase during NW in the Parkinson group was longer than in the healthy control ($p < 0.001$). In Parkinson group, NW was longer than FW ($p = 0.003$; Table 6).

The time to propulsive peak force was not affected by group ($p = 0.064$) but was affected by modality ($p = 0.037$). Moreover, a significative interaction group*modality was identified ($p = 0.003$). The time of braking phase during NW in the Parkinson group was longer than in the healthy control ($p = 0.004$). In Parkinson group, NW was longer than FW ($p = 0.001$; Table 6). The time to loading response peak, the time to midstance force, the time to braking peak force, the time of propulsive phase were not affected by group or modality, and significative interactions were not identified (Table 6).

The terminal stance impulse was affected by group ($p < 0.001$) and modality ($p = 0.006$). Moreover, a significative interaction group*modality was identified ($p = 0.009$). The terminal stance impulse during NW in the Parkinson group was greater than in the healthy control ($p < 0.001$). In Parkinson group, NW was greater than FW ($p < 0.001$; Table 6).

The braking impulse was not affected by group (p = 0.665), but it was affected by modality (p = 0.021). Moreover, a significative interaction group*modality was identified (p = 0.010). In the Parkinson group, the braking impulse during NW was greater than FW (p = 0.002; Table 6).

The total vertical and propulsive impulses were not affected by group and modality (figure 1). Moreover, a significative interaction group*modality was identified (p = 0.039 and 0.014; respectively, Table 6). The loading response impulse was not affected by group or modality, and significative interactions were not identified (Table 6).

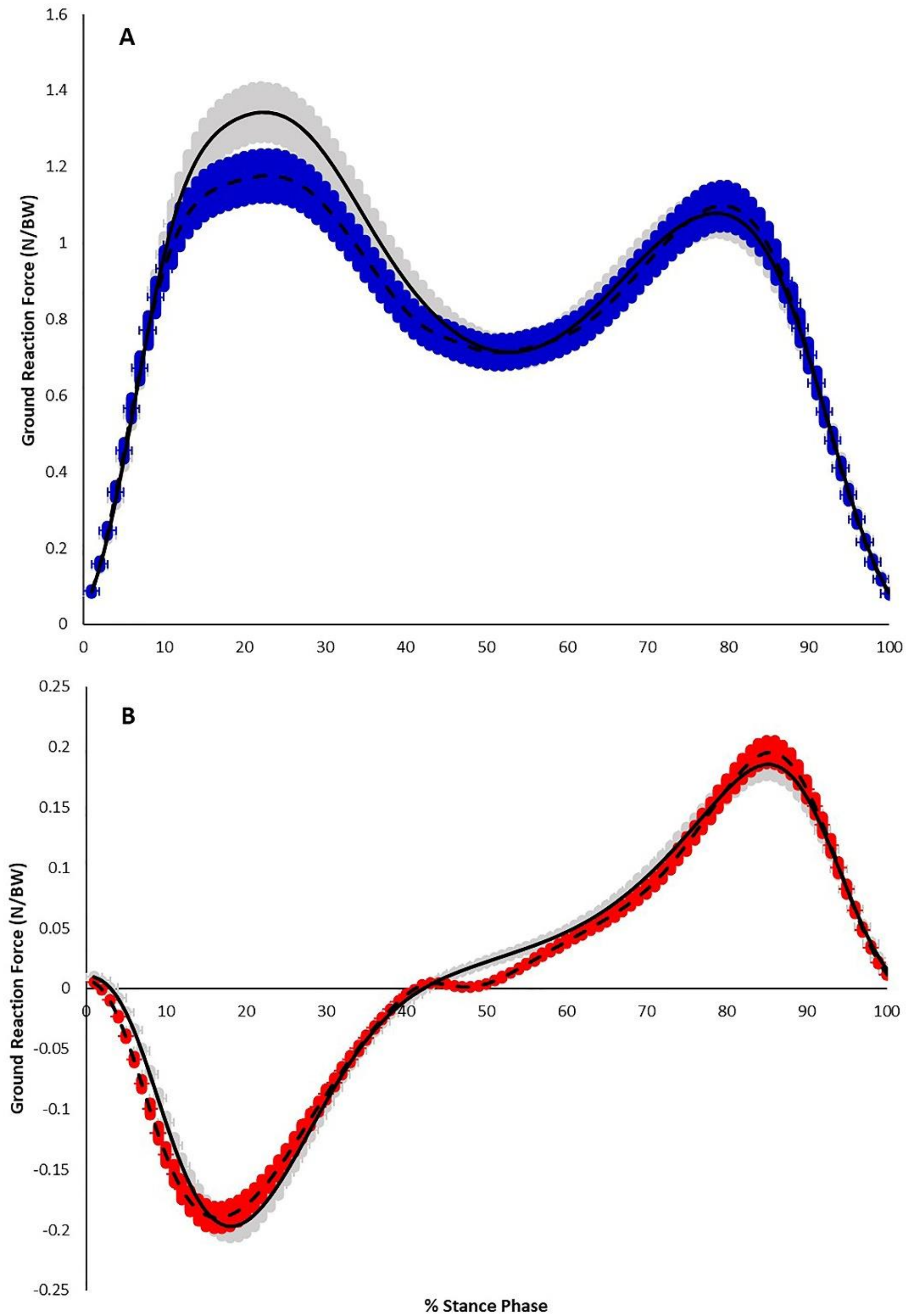

Figure 9 Vertical (A) and anteroposterior (B) ground reaction force during fast walking speed in the Parkinson group as a function of percentual of stance phase. Continue lines (mean from free walking); interrupted lines (mean Nordic walking); red shaded line (standard deviation from Nordic walking); gray shared line (standard deviation from free walking).

3.3.1.2 Spatiotemporal parameters

The contact time was not affected by group (p = 0.828), but it was affected by modality (p < 0.001). Moreover, a significative interaction group*modality was not identified (p = 0.552). The contact time during NW was greater than FW (p <0.001; Table 6), group-independent.

The fast-walking speed was affected by group (p < 0.001), but it was not affected by modality (p = 0.678). Moreover, a significative interaction group*modality, was not identified (p = 0.198). The fast-walking speed in the Parkinson group was lower than in the healthy control (p < 0.001; Table 6), modality-independent.

The step frequency was not affected by group (p = 0.202), but it was affected by modality (p = 0.005). Moreover, a significative interaction group*modality was not identified (: p = 0.960). The step frequency during the NW was lower than FW (p = 0.005; Table 6).

The step length was affected by group (p < 0.001), but it was not affected by modality (p = 0.618). Moreover, a significative interaction group*modality was not identified (p = 0.209). The step length in the Parkinson group was lower than the healthy control (p <0.001; Table 6).

Table 6 Kinect and spatiotemporal variables during fast walking speed

Variables	Healthy control		Parkinson group		p-value		
	FW	NW	FW	NW	Group	Modality	Group* Modality
Fast walking speed (m/s)	1.60 ± 0.33	1.67 ± 0.24	1.27 ± 0.17	1.17 ± 0.13	**0.000**	0.678	0.198
Step frequency (Hz)	1.80 ± 0.10	1.71 ± 0.12	1.76 ± 0.10	1.66 ± 0.12	0.202	**0.005**	0.960
Step length (m)	0.89 ± 0.19	0.97 ± 0.17	0.72 ± 0.10	0.70 ± 0.08	**0.000**	0.618	0.209
Contact time (s)	0.57 ± 0.04	0.62 ± 0.07	0.56 ± 0.03	0.63 ± 0.06	0.828	**0.000**	0.552
F1 Loading response peak force (N/BW)	1.35 ± 0.15	1.35 ± 0.15	1.33 ± 0.06	1.27 ± 0.08	0.111	0.278	0.337
F2 Midstance force (N/BW)	0.64 ± 0.09	0.53 ± 0.12	0.69 ± 0.15	0.67 ± 0.14	**0.007**	0.087	0.160
F3 Terminal stance peak force (N/BW)	1.10 ± 0.10	1.11 ± 0.09	1.10 ± 0.08	1.17 ± 0.06	0.249	0.059	0.243
F4 Braking peak force (N/BW)	-0.19 ± 0.02	-0.20 ± 0.04	-0.18 ± 0.03	-0.20 ± 0.03	0.876	0.212	0.328
F5 Propulsive peak force (N/BW)	0.20 ± 0.04	0.20 ± 0.06	0.17 ± 0.04	0.20 ± 0.04	0.260	0.259	0.291
T1 Time to loading response peak force (s)	0.13 ± 0.02	0.13 ± 0.02	0.13 ± 0.02	0.12 ± 0.02	0.627	0.471	0.804
T2 Time to midstance force (s)	0.30 ± 0.02	0.29 ± 0.03	0.29 ± 0.02	0.30 ± 0.03	0.979	0.819	0.085
T3 Time to terminal peak force (s)	0.45 ± 0.03	0.44 ± 0.03	0.43 ± 0.03	0.48 ± 0.04 † §	0.256	0.064	**0.003**
T4 Time to braking peak force (s)	0.11 ± 0.01	0.11 ± 0.01	0.10 ± 0.01	0.10 ± 0.01	0.487	0.947	0.821
T5 Duration of braking phase (s)	0.24 ± 0.03	0.23 ± 0.03	0.24 ± 0.02	0.27 ± 0.02 † §	**0.002**	**0.038**	**0.009**
T6 Time to propulsive peak force (s)	0.48 ± 0.03	0.47 ± 0.04	0.47 ± 0.03	0.52 ± 0.04 † §	0.064	**0.037**	**0.003**
T7 Duration of propulsive phase (s)	0.25 ± 0.02	0.25 ± 0.01	0.24 ± 0.02	0.26 ± 0.03	0.641	0.060	0.053
I1 Loading response impulse (N.s/BW)	286.4 ± 36.6	264.4 ± 36.2	271.9 ± 27.7	265.8 ± 21.1	0.474	0.126	0.386
I2 Terminal stance impulse (N.s/BW)	204.6 ± 32.0	205.8 ± 27.3	214.3 ± 31.9	270.7 ± 39.4† §	**0.000**	**0.006**	**0.009**
I3 Total vertical impulse (N.s/BW)	491.0 ± 29.2	482.0 ± 40.3	482.3 ± 30.9	530.2 ± 70.6	0.159	0.165	**0.039**
I4 Braking impulse (N.s)	-23.5 ± 4.9	-23.2 ± 4.8	-20.8 ± 3.7	-26.9 ± 3.0 †	0.665	**0.021**	**0.010**
I5 Propulsive impulse (N.s/BW)	30.7 ± 8.7	27.3 ± 7.9	25.9 ± 6.3	32.9 ± 3.8	0.923	0.398	**0.014**

Values are presented by means and standard deviation. Free walking (FW); Nordic walking (NW). Superscript symbols indicate statistically significant differences ($p < 0.05$) within-effect (with versus without poles) in the Parkinson group (†), Healthy Control (‡), between-effect (Parkinson versus Healthy control) in FW and NW conditions (§).

3.3.2 Nordic running

3.3.2.1 Kinetic parameters

In figure 10 are illustrated the vertical and anteroposterior curves of the NR and free running from the Parkinson group. The propulsive peak force was affected by group ($p < 0.001$), but it was not affected by modality ($p = 0.892$). Moreover, a significative interaction group*modality was identified ($p = 0.015$). During NR, the propulsive peak force was lower in the Parkinson group than in the healthy control ($p < 0.001$; Table 7). The loading response peak force and braking peak force were not affected by group or modality, and significative interactions were not identified (Table 7).

The loading response impulse was affected by group ($p = 0.001$), but it was not affected by modality ($p = 0.213$). Moreover, a significative interaction group*modality was identified ($p = 0.032$). The loading response impulse during NR in the Parkinson group was lower than in the healthy control ($p = 0.001$; Table 7).

The propulsive impulse was affected by group ($p < 0.002$), but it was not affected by modality ($p = 0.083$). Moreover, a significative interaction was not identified ($p = 0.096$). The propulsive impulse in the Parkinson group was lower than in the healthy control ($p < 0.001$; Table 7).

The time to loading response peak force, time to braking peak force, time of braking phase, time to propulsive peak force, time of propulsive phase, braking impulse were not affected by group or modality, and significative interactions were not identified (Table 7).

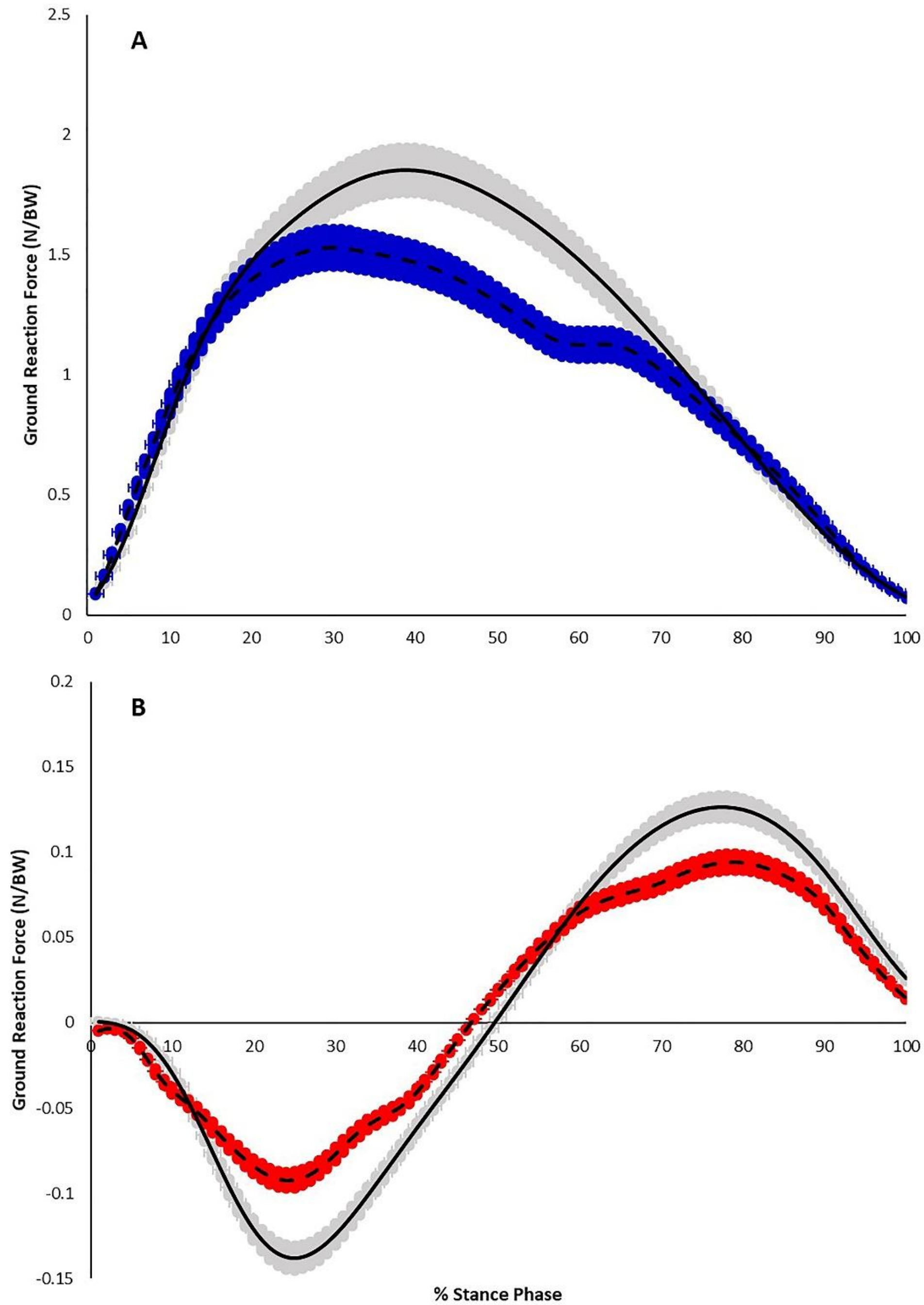

Figure 10 Vertical (A) and anteroposterior (B) ground reaction force during free and Nordic running in the Parkinson group as a function of percentual of stance phase. Continue lines (mean from free walking); interrupted lines (means Nordic walking); red shaded line (standard deviation from Nordic walking); gray shared line (standard deviation from free walking).

3.3.2.2 Spatiotemporal parameters

The running speed was affected by group ($p < 0.001$), but it was not affected by modality ($p = 0.814$). Moreover, a significative interaction group*modality was not identified ($p = 0.600$). The running speed in the Parkinson group was lower than in the healthy control ($p < 0.001$; Table 7), modality-independent.

The step frequency was not affected by group ($p = 0.538$), but it was affected by modality ($p < 0.001$). Moreover, a significative interaction group*modality was not identified ($p = 0.384$). The step frequency during NW was lower than FW ($p < 0.001$; Table 7).

The step length was affected by group ($p < 0.001$) and modality ($p < 0.001$). Moreover, a significative interaction group*modality was identified ($p = 0.029$). The step length during NW and FW was lower in the Parkinson group than in the healthy control ($p < 0.001$ and 0.007, respectively). In the healthy control, the step length was greater during NW than FW ($p < 0.001$; Table 7). The contact time was not affected by group or modality, and significant interactions were not identified (Table 7).

Table 7 Kinect and spatiotemporal variables during free and Nordic running

Variables	**Healthy control**		**Parkinson group**		**p-value**		
	FR	NR	FR	NR	Group	Modality	Group* Modality
Self-selected running speed (m/s)	1.86 ± 0.29	1.93 ± 0.31	1.49 ± 0.21	1.47 ± 0.29	**0.000**	0.814	0.600
Step frequency (Hz)	2.85 ± 0.33	2.32 ± 0.51	2.89 ± 0.45	2.11 ± 0.55	0.538	**0.000**	0.384
Step length (m)	0.65 ± 0.07	0.87 ± 0.17 ‡	0.52 ± 0.07 §	0.57 ± 0.11§	**0.000**	**0.000**	**0.029**
Contact time (s)	0.36 ± 0.05	0.40 ± 0.05	0.36 ± 0.07	0.39 ± 0.08	0.693	0.126	0.643
F1 Loading response peak force (N/BW)	1.81 ± 0.27	1.69 ± 0.27	1.80 ± 0.18	1.69 ± 0.20	0.957	0.108	0.923
F4 Braking peak force (N/BW)	-0.15 ± 0.03	-0.16 ± 0.01	-0.14 ± 0.02	-0.15 ± 0.02	0.098	0.182	0.849
F5 Propulsive peak force (N/BW)	0.14 ± 0.03	0.15 ± 0.02	0.12 ± 0.02	0.10 ± 0.02 §	**0.000**	0.892	**0.015**
T1 Time to loading response peak force (s)	0.15 ± 0.03	0.15 ± 0.03	0.14 ± 0.02	0.14 ± 0.02	0.247	0.572	0.684
T4 Time to braking peak force (s)	0.10 ± 0.01	0.10 ± 0.01	0.10 ± 0.01	0.09 ± 0.01	0.391	0.795	0.108
T5 Duration of braking phase (s)	0.18 ± 0.03	0.20 ± 0.03	0.19 ± 0.04	0.18 ± 0.04	0.630	0.577	0.285
T6 Time to propulsive peak force (s)	0.28 ± 0.05	0.31 ± 0.04	0.28 ± 0.06	0.28 ± 0.06	0.623	0.333	0.442
T7 Duration of propulsive phase (s)	0.09 ± 0.02	0.10 ± 0.01	0.09 ± 0.03	0.10 ± 0.03	0.795	0.224	0.755
I1 Loading response impulse (N.s/BW)	166.1 ± 14.6	172.2 ± 10.8	158.1 ± 26.4	134.8 ± 30.3 §	**0.001**	0.213	**0.032**
I4 Braking impulse (N.s)	-14.0 ± 3.9	-15.4 ± 2.2	-13.5 ± 2.6	-14.8 ± 3.1	0.504	0.123	0.957
I5 Propulsive impulse (N.s/BW)	14.7 ± 2.1	17.5 ± 1.9	12.8 ± 2.6	12.8 ± 3.5	**0.000**	0.083	0.096

Values are presented by means and standard deviation. Free running (FR); Nordic running (NR). Superscript symbols indicate statistically significant differences ($p < 0.05$) within-effect (with versus without poles) in the Parkinson group (†), Healthy Control (‡), between-effect (Parkinson versus Healthy control) in FW and NW conditions (§).

3.4 Discussion

This study compared the kinetic and spatiotemporal parameters during walking at fast speed and running with and without NW poles in people with PD and healthy control. We partially accept our hypothesis because the use of NW poles increased the vertical (terminal stance) and the anteroposterior components (braking and propulsive) of the GRF in the Parkinson group. During NR, the vertical components of the GRF were decreased in comparison to free running, and anteroposterior components in the Parkinson group remain unchanged compared to the healthy controls. This study also indicates that poles modify the gait spatiotemporal parameters of PD, reducing step frequency both at fast walking and running and the step length during walking remained unchanged compared to the healthy control.

We evaluated the stance phase of walking, which is subdivided by events: initial contact (touch-down), loading response, midstance, and terminal stance (take-off) (NOVACHECK, 1998). During NW, the terminal stance, the time to terminal peak force, and the time to propulsive peak were greater in the Parkinson group than in the healthy control. Moreover, in the Parkinson group, these variables were greater during NW than FW. These responses could be mechanically explained by longer contact time, unchanging the terminal stance, and propulsive peak force (KNUDSON, 2007). These second-half stance components increased are likely associated with gastrocnemius inefficiency in people with PD (ISLAM et al., 2020). The gastrocnemius is the primary in charge of forward gait propulsion (GOTTSCHALL; KRAM, 2003). Functionally, decreased activity can reduce walking speed and postural balance across the vertical axis (ISLAM et al., 2020).

The braking impulse and time of braking phase in the Parkinson group were greater during NW than FW. Also, the time of braking phase was longer in the Parkinson group compared to the healthy control. Mechanically, it can be explained by a longer contact time and the unchanged braking peak force (KNUDSON, 2007). Functionally, the first half stance components increase may be related to anterior tibial disorders, exhibited in the Parkinson group (ISLAM et al., 2020), and consequent inability to generate sufficient braking components under time-critical conditions (BISHOP et al., 2003). Decreased tibial anterior activity reduces foot clearance and modifies foot contact patterns, influencing the risk of falling (ISLAM et al., 2020). In addition, the increased braking and propulsive components during NW may be associated with a decreased range of hip and knee motion (ZANARDI et al., 2021) during the terminal stance phase (DIPAOLA et al., 2016), followed by a higher co-contraction of the ankle muscles during Parkinson's gait (MONTEIRO et al., 2016b). Such modifications may influence the appropriate weight transfer in preparation for steps and may result in a higher metabolic cost of walking (BANASZKIEWICZ; KADER, 2014; DIPAOLA et al., 2016; MONTEIRO et al., 2016b).

Although the NW does not significantly affect impulses, the longer contact time during the NW probably explains the significative interactions on the total vertical and propulsive impulses due to the more extended force production time. The longer contact time is affected mainly by the time of braking phase, the time to terminal peak force, and the time to propulsive peak. These components were longer during NW in the Parkinson group than in the healthy control and FW. The prolonged contact time is the main reason that could explain the reduced step frequency in the Parkinson group during the NW. However, these changes could not alter the walking speed in the Parkinson group, maintaining similarities between groups, unlike young healthy (ENCARNACIÓN-MARTÍNEZ; PÉREZ-SORIANO; LLANA-BELLOCH, 2015). These results probably occur because the step length remained similar during NW. This compensation leads to a modified gait strategy that does not allow the increased speed in PD. People with PD have lower self-selected (ZANARDI et al., 2021) and fast (KUHMAN; HAMMOND; HURT, 2018) walking speed during FW, following our results other studies, probably due to the reduced step length in the PD group.

We observed by means group-effect that the pattern application force was similar between groups. Different from what happens during self-selected walking speed previously reported (BISHOP et al., 2003; SHARIFMORADI; FARAHPOUR, 2016), in which the vertical (terminal stance) and anteroposterior (braking and propulsive) force components are reduced. The exception is the greater midstance force peak in the Parkinson group than in the healthy control, which may be due to flexed posture of the leg and decreased knee extension in the midstance of the Parkinson group (SHARIFMORADI; FARAHPOUR, 2016). Similarly, the step frequency remains similar during fast walking speed between the Parkinson group and healthy control. This result differs from the reported self-select walking speed between groups in another study (ZANARDI et al., 2021). Thus, the fast-walking speed appears to modify the Parkinson's pattern gait. Also, our results indicate that the use of poles during fast walking speed appears to modify the patter gait by reducing the effect of motor symptoms of PD.

We evaluated the stance phase of the running gait cycle, such: initial contact (touch-down) and terminal stance (take-off) (NOVACHECK, 1998). Carry out this discussion was challenging due to the lack of running studies in people with PD. Nevertheless, alterations were observed confronting our results with young and old healthy previously described in the literature.

The loading response impulse was lower in the Parkinson group than in the healthy control (group-effect), but your force and time components remain similar. The reduced loading response impulse may indicate better shock absorption and protects against joint cartilage damage. (NOVACHECK, 1998), supporting the hypotheses that redistribute the bodyweight could decrease the load on the lower limbs (HAGEN; HENNIG; STIELDORF, 2011; WILLSON et al., 2001). The unchanged braking impulse (group and modality effect) in the Parkinson group may be related to the decrease of step length (group and modality effect) as the foot is planted closer to the body at touch-down (NILSSON; THORSTENSSON, 1989). The propulsive impulse was lower in the Parkinson group than in the healthy control (group-effect). It can be explained partly by the decreased propulsive peak force and unaltered time to propulsive peak force (KNUDSON, 2007).

Regarding the NR, the propulsive impulse was not affected by modality, but the propulsive peak force was lower in the Parkinson group than in the healthy control. The unchanged propulsive impulse is associated with a similar time to propulsive peak (KNUDSON, 2007). In healthy young, changes in the anteroposterior direction of the GRF are expected, especially with greater acceleration to overcome limitations such as air resistance (NILSSON; THORSTENSSON, 1989). As far as we are concerned, Parkinson presented a modified pattern during NR, probably from lower limb neuromuscular disorders (ISLAM et al., 2020), similar to what happens during fast-walking speed.

Furthermore, the running mechanism needs greater muscular effort to maintain the motion of the center of mass (CAVAGNA; LEGRAMANDI; PEYRÉ-TARTARUGA, 2008). The stretch-shorten cycle of the muscle-tendon units occurs at each step of running with more mechanical energy oscillation the vertical and forward oscillations (CAVAGNA; LEGRAMANDI; PEYRÉ-TARTARUGA, 2008). The main reason for the decrease in the vertical and anteroposterior GRF components may be related to disorders in muscle activity in people with PD. The impulse loading response may be explained by anterior tibial disorders (NOVACHECK, 1998). This muscle is considering the ankle dorsiflexion (concentric contraction) actions to give clearance in swing, providing the ground contact with the hindfoot initial, and controlling the lowering of the forefoot to the ground (eccentric contraction) during the first part of stance (NOVACHECK, 1998).

On the other hand, the worse impulse components in the Parkinson group may be associated with lower efficiency of the gastrocnemius in PD (ISLAM et al., 2020). During the second half of the stance phase, the gastrocnemius plays the role of pushing forward by plantarflexing the foot (NOVACHECK, 1998). Furthermore, we speculate that these changes may also be associated with a reduced knee range of motion during the stance phase, similar to walking (DIPAOLA et al., 2016). We did not find studies on the range of motion with people in PD. All these mechanisms may induce lower energy elastic store, lower vertical mechanical work, and unchanged work to sustain forward speed, similarly to old people (CAVAGNA; LEGRAMANDI; PEYRÉ-TARTARUGA, 2008), impacting metabolic cost (NOVACHECK, 1998).

Regarding the spatiotemporal paraments, although the step frequency was not affected by group, the running speed of the Parkinson group was slower than the healthy control (group-effect), and the main reason may be the smaller step length (group-effect). While the speed was slower only during fast walking speed, no significative group-effect on step frequency suggests that the Parkinson group present a modified pattern during free running compared to the self-selected walking speed reported previously (ZANARDI et al., 2021).

Conversely, the step frequency decreased during NR in both groups. These reductions are a significant impact on the Parkinson group. This population is characterized by greater step frequency and smaller step length, which leads to lower self-selected walking speed during FW (ZANARDI et al., 2021). Our study showed that the running speed remains similar between the group during NR. Although the step length was smaller in the Parkinson group than in the healthy control during NR, these changes could not modify the running speed. Therefore, these outcomes indicate the NR leads to a decrease the motor symptoms in the Parkinson group.

The NW is characterized by contralateral coordination between arms and legs, where the pole held on the opposite side of the stepping foot is planted diagonally backward. People with PD appear not to benefit fully from the use of poles, probably due to upper limb movement disorders, such as increased arm swing asymmetry, reduced elbow, shoulder (KOH et al., 2019), and trunk (CANO-DE-LA-CUERDA et al., 2020) range of motion, and modified motor activity and inter-limb coordination (WU; HALLETT; CHAN, 2015). These components probably contribute not to increase the vertical and anteroposterior peak forces and walking speed.

Otherwise, it is essential to highlight that, at best of our knowledge, we are the first to present biomechanical results of running with poles in people with PD. The limitations of the study were: people with mild to moderate levels of gait restriction narrow range, we recruited only people with PD in stages between 1 and 1.5 (1 ± 0.5) based on H&Y scale, and no cognitive tests were performed on the people with PD. Furthermore, we tested the free running and NR in a small range of speeds.

3.5 Conclusion

Our results assist in discussing the rehabilitation of people with PD based on the GRF and spatiotemporal gait parameters using poles during running and fast walking. This study showed that NW poles increased vertical components (terminal stance) and anteroposterior components (braking and propulsive) of the GRF in people with PD, indicating compensatory adjustments to disorders in lower limb muscle activity. During NR, the vertical components of the GRF were decreased, and anteroposterior components in the Parkinson group remain unchanged compared to the healthy controls. This study also indicates that poles modify the spatiotemporal gait of PD, reducing step frequency both at fast walking and running and unchanged the step length during walking, compared to the healthy control. Thus, our results suggest NW and NR modify gait patterns in the Parkinson group and reduces PD motor symptoms. The use of poles during walking and running appears to be a functional and safe activity, and people with PD tend to benefit from exercise programs to improve these GRF and spatiotemporal outcomes.

Conflict of interest statement

This study has no conflict of interest

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CHAPTER 4

4.1 General discussion

Our study observed differences between in step physiomechanics the Parkinson's disease (PD) people and healthy controls. Some findings partially corroborated the literature, and others gave us new insights to the discussion about the locomotion of people with PD using poles. In the chapter 2, we evaluated for the first time the fluctuations of mechanical kinetic and potential energies associated with the body center of mass during gait of people with PD at commonly used speeds. Our main objective was to compare the mechanical, pendulum recovery, and spatiotemporal determinants with and without Nordic walking (NW) poles.

We found that the NW poles increased the vertical and horizontal mechanical energy fluctuations. The enhanced fluctuation resulted in a greater pendulum-like energy recovery. The higher total mechanical work in PD people during NW could be explained due to increased external mechanical work. These results corroborate findings in NW instructors (PELLEGRINI et al., 2017), so it seems that the pendular mechanism still maintains in people PD during NW, which impact energetics and apparent efficiency (PEYRÉ-TARTARUGA et al., 2021). However, differently to what occurs in NW instructor where the external mechanical work remains unchanged, the PD people increase the external mechanical using poles in comparison to free walking (FW). We speculate that this result is, at least partly, due to the unusual speed in people with PD. Previously, lower mechanical work was observed even at fast walking during FW due to typical muscle stiffness related to disease progression (KUHMAN; HAMMOND; HURT, 2018). Therefore, our results indicate that walking with poles seems to modify PD motor symptoms.

The reduction in step length and increase in step frequency during NW indicates that the poles generate modified spatiotemporal adjustments in people with PD. Healthy people walking with poles increase step length and reduce step frequency (PELLEGRINI et al., 2017). We believe that these changes are due to a modified NW technique due to the limitations imposed by PD. During the data collection, even with the warm-up period and considering that people with PD have experience with the NW technique, we identified that some subjects with the more advanced stages of the disease had difficulty maintaining the correct technique. Future studies evaluating the execution of the technique using kinematic methods at different walking speed intensities in people with PD are necessary.

Furthermore, our findings add information in the discussion about the energetics of FW of PD people previously reported (DIPAOLA et al., 2016; NARDELLO et al., 2017). We observed high total mechanical work and lower recovery in PD compared to healthy controls. These changes may explain the low walking economy in PD (NARDELLO et al., 2017).

In the chapter 3, we describe the first insights on NW poles and ground reaction forces (GRF) gait parameters of people with PD during high speeds. Our main target was to compare kinetic and spatiotemporal parameters at fast walking and self-selected running speeds with and without NW poles.

During NW, the vertical components (terminal stance) increased. This result differ from what was observed in PD people during FW. The terminal stance components are reduced (SHARIFMORADI; FARAHPOUR, 2016). On the other hand, the anteroposterior components (braking and propulsive) were increased during NW. Again, these changes diverge from those found during FW. The propulsion (SHARIFMORADI; FARAHPOUR, 2016) and braking (BISHOP et al., 2003) are reduced.

Healthy people the vertical and anteroposterior components in the touch-down are increase and the vertical and anteroposterior components in the take-off are reduce, when using walking poles (ENCARNACIÓN-MARTÍNEZ; PÉREZ-SORIANO; LLANA-BELLOCH, 2015; HAGEN; HENNIG; STIELDORF, 2011). Furthermore, these parameters seem depend on the walking technique with poles (WILSON et al., 2001). This pattern increases and decrease is maintained from self-select walking speed to fast-walking speed. The vertical and anteroposterior GRF components increase during the take-off are expected, due to the foot and pole force directions have opposite orientations at that moment of the walking cycle (HAGEN et al., 2011; STIEF et al., 2008). The reduction the vertical and anteroposterior GRF components during touch-down could be interpreted that the increase in speed is caused in part by a more dynamic use of the poles, resulting in a reduction of the parameters related to take-off (ENCARNACIÓN-MARTÍNEZ; PÉREZ-SORIANO; LLANA-BELLOCH, 2015. These findings are supported because the use of NW poles reduces muscle activity in the lower limb extremities during the touch-down.

However, during the take-off phases, the upper body's energy expenditure is increased and the lower limbs' is decreased (SUGIYAMA et al., 2013).

The GRF components' changes are associated with alterations in muscle activity of anterior tibialis and reduced gastrocnemius performance in PD (ISLAM et al., 2020). Thus, the vertical components (terminal stance) and anteroposterior (braking and propulsive) increased suggest that the NW induces to compensatory adjustments in these disorders, resulting in an improved stability and propulsion in Parkinson's gait.

The maximal values in vertical GRF were reduced during Nordic running (NR) in comparison to free running in both groups. Although there is a lack of studies in the literature, our results agree with previous findings in healthy people (KWON; BOLT; SHIM, 2001). (KŮTEK; TVRZNÍK, 2014). In addition, the plantar pressure is also reduced during NR (DAVIAUX et al., 2013; KŮTEK; TVRZNÍK, 2014), indicating a redistribution of mechanical work in limbs. Thus, a reduction in lower limb overload may be a strategy to compensate for lower limb muscle activation disorders, which may be maintained during running.

The step frequency was reduced during NR to both groups. Since the step frequency is increased in people with PD (ZANARDI et al., 2021), our findings on NR suggest that the spatiotemporal differences may be minimized during NR. Perhaps, a wider range of speeds could better illustrate these adjustments in people with PD.

In summary, our results from both studies indicate that using NW poles can impact the energetics of locomotion in people with PD. We have developed a conceptual model to explain the fluctuating effect of the poles from the external forces generated to impact on the spatiotemporal, mechanical, and energetic components of locomotion (Figure 11).

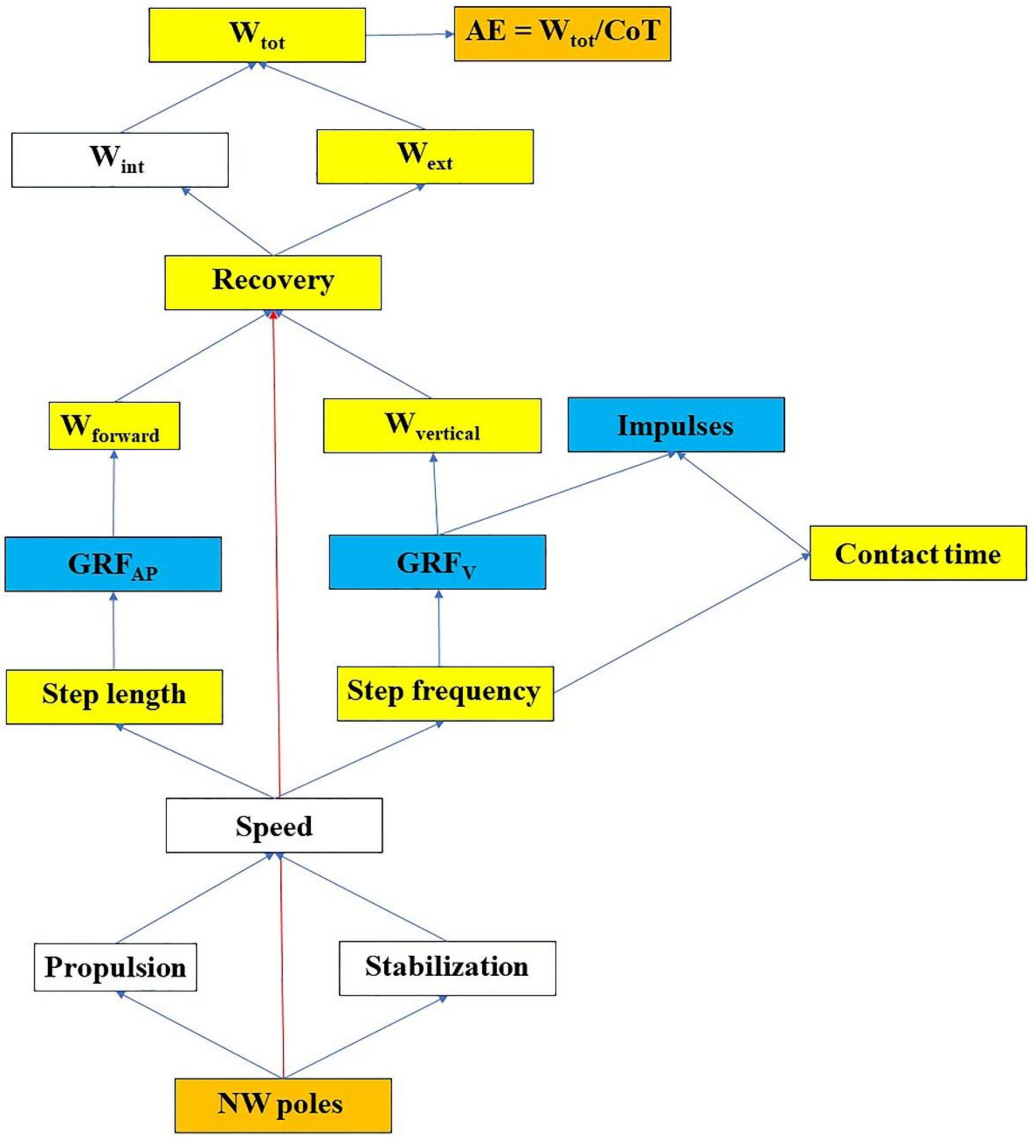

Figure 11 Conceptual model of energy cost and Nordic walking poles. Vertical ground reaction force components (GRF_V); anteroposterior ground reaction force components (GRF_{AP}); forward mechanical work ($W_{forward}$); vertical mechanical work ($W_{vertical}$); internal mechanical work ($W_{internal}$); external mechanical work ($W_{external}$); apparent efficiency (AE); energetic cost (CoT).

In our dissertation, we study the external mechanical energies through König's theorem (Fenn's approach) to elucidate the determinants of the locomotion energy cost of PD people via pendulum-like mechanism. Since chemical energy is used to produce mechanical work, the result of this interaction is apparent efficiency. The pendulum mechanism predicts that cost will be lowest and apparent efficiency highest when energy recovery is highest (PEYRÉ-TARTARUGA, 2021).

Thus, the conceptual model illustrates the experimental design of this dissertation. It shows how NW poles can impact the locomotion energetics of people with PD by increasing the fluctuations of external energies. Future studies could add to this analysis the NW muscle activity and mass model during NR to better understand the locomotion energetics of people with PD.

4.2 General conclusion

We concluded that pendulum-like recovery was optimized acutely during NW in people with PD. This optimization due to a significant increase in vertical and forward energy fluctuations using poles. In addition, NW alters gait mechanics in Parkinson’s group, increasing the total work due to internal work.

The PD people showed spatiotemporal gait modify, increased step frequency, and reduced step length during NW and FW. Our findings partly justify the lower walking economy in PD during FW due to higher total work and reduced pendulum-like mechanism at commonly used speeds.

The NW during fast-walking speed increased vertical (terminal stance) and anteroposterior (braking and propulsive) components of the GRF in people with PD, indicating compensatory adjustments to disorders in lower limb muscle activity.

The NR decreased the vertical components of the GRF and remained unchanged anteroposterior components in PD people. Also, the use of poles during fast-walking speed and running reduces step frequency in PD.

Finally, NW and NR are functional and safe activities. Therefore, it can be a compelling strategy for rehabilitation because of its potential to improve functional mobility, increase pendulum-like energy recovery, external mechanical work, kinetic components and impacts the energy cost of PD locomotion.

4.3 References

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4.4 Supplement material

TERMO DE CONCENTIMENTO LIVRE E ESCLARECIDO (TCLE)

Título da Pesquisa: EFEITOS DA UTILIZAÇÃO DE BASTÕES SOBRE A FISIOMECÂNICA DA CAMINHADA EM PESSOAS COM DOENÇA DE PARKINSON.

Pesquisador Responsável: Prof. Dr. LEONARDO ALEXANDRE PEYRÉ-TARTARUGA

Nome do Participante:____

Você está sendo convidado a participar de uma pesquisa cujo objetivo é comparar em diferentes velocidades de caminhada os parâmetros Mecânicos (trabalho do seu musculo durante a caminhada), do Mecanismo do Pendular (como você caminha) com e sem bastões de Caminhada Nórdica pessoas com Doença de Parkinson e pessoas saudáveis praticantes de Caminhada Nórdica.

A pesquisa será realizada no Laboratório de Avaliação Pesquisa em Atividade Física (LAPAFI) da Pontifícia Universidade Católica do Rio Grande do Sul (PUCRS) e no Laboratório de Pesquisa do Exercício (LAPEX), na Escola de Educação Física, Fisioterapia e Dança (ESEFIDE).

Os participantes serão organizados em dois grupos pelos pesquisadores, o grupo Parkinson (pessoas acima de 50 anos e com o diagnostico clinico da doença de Parkinson) e grupo de pessoas saudáveis (pessoas acima de 50 anos de idade e saudáveis), ambos compostos por 10 pessoas.

Caso você aceite participar da pesquisa, deverá realizar os seguintes procedimentos:

- Responder a um questionário sobre sua data de nascimento, idade, tempo de que você prática caminhada nórdica, o horário que toma a medicação (apenas para pessoas com doença de Parkinson);
- Responder o Questionário Internacional de Atividade Física (IPAQ) (que avalia quão ativo você é, medindo a quanto tempo você passou realizando atividade física durante sua última);
- Participar de medições de sua massa corporal, estatura (altura) e comprimento do membro inferior (perna),

- Participar da aplicação da escala motora UPDRS III (que avalia o quanto a Doença de Parkinson está afetando o seu dia a dia), e da escala de Hoehn & Yahr (que avalia o quanto a Doença de Parkinson está progredindo)
- Participar de testes de análise cinética da caminhada e corrida (caminhada nórdica e caminhada livre) sobre uma passarela de madeira de 6 metros de comprimento e 1,20 metros de largura, com 8 plataformas de força (que medi a força que você aplica no solo durante a caminhada) fixadas no centro da passarela. Você terá que caminhar em cinco velocidades diferentes a saber: 2 e $5 km.h^{-1}$, a sua velocidade confortável, a sua velocidade máxima, a sua velocidade autosselecionada de corrida (que serão controladas através de um cronometro), você fará 10 testes em cada velocidade, a ordem desse processo será determinada através de sorteio. Enquanto caminha, você será filmado para registro das avaliações. Você terá que visitar o laboratório 3 vezes (uma hora de duração cada visita), para realizar essas avaliações.

O estudo apresenta um risco considerado mínimo pelo constrangimento eventual que você possa ter ao responder as perguntas dos questionários e algum desconforto na participação nas avaliações. Também é reconhecido um risco considerado mínimo na execução dos movimentos, durante os testes de caminhada, assim como, na realização de alguns testes para testar evolução da sua doença (caso seja portador da doença de Parkinson).

Dentre estes, estão possíveis perdas no equilíbrio, que serão amenizadas pela supervisão constante dos professores, monitores e avaliadores durante toda a avaliação. Caso você se sinta constrangido ou desconfortável em alguma das etapas dos procedimentos de coleta de dados, poderá abandonar a pesquisa em qualquer momento.

O benefício direto do estudo está relacionado à possibilidade de você aprimorar seu equilíbrio, postura, qualidade na caminhada, melhorando a sua qualidade de vida e sua aptidão física visto que as intervenções realizadas podem ser métodos complementares na sua reabilitação.

O presente documento é baseado no item IV das Diretrizes e Normas Regulamentadoras para a pesquisa em saúde, do Conselho Nacional de Saúde

(Resoluções 466/12 e 510/2016), e será assinado em duas vias, de igual teor, ficando uma via em seu poder ou de seu representante legal e outra com o pesquisador responsável. Os seus dados serão sempre tratados confidencialmente, você não será identificado(a) por nome, e os resultados deste estudo serão usados para fins científicos.

Sua participação no estudo é voluntária, de forma que, caso você decida não participar, você não terá nenhum comprometimento por esta decisão. Você não terá custo e nem receberá por participar. Se necessário, os gastos referentes ao transporte poderão ser ressarcidos conforme combinação com o pesquisador responsável pela pesquisa. Sua participação não é obrigatória e, a qualquer momento, poderá desistir e retirar seu consentimento.

Caso você tenha dúvidas, poderá entrar em contato com: o pesquisador responsável Prof. Dr. Leonardo Alexandre Peyré-Tartaruga pelo telefone (51) 98406-3793, a Escola de Educação Física, Fisioterapia e Dança – Rua Felizardo, 750, Jardim Botânico – POA/RS pelo telefone (51) 3308-5817; o Laboratório de Pesquisa do Exercício, da Escola de Educação Física, Fisioterapia e Dança, UFRGS pelo telefone (51) 3308-5817; ou Comitê de Ética em Pesquisa da UFRGS (Av. Paulo Gama, 110 - Sala 317 – POA/RS) pelo telefone (51) 3308-3738, de segunda à sexta, das 8h às 17h.

Declaração do paciente

Eu,____, fui informado(a) dos objetivos da pesquisa acima de maneira clara, tendo tempo para ler e pensar sobre a informação contida no termo de consentimento antes de participar do estudo. Recebi informação a respeito dos procedimentos de avaliação realizados e esclareci minhas dúvidas. O pesquisador responsável pela pesquisa certificou-me também de que todos os dados coletados serão mantidos em anonimato e de que a minha privacidade será mantida. Também sei que caso existam gastos adicionais, estes serão absorvidos pelo orçamento da pesquisa. Caso tiver novas perguntas sobre este estudo, poderei entrar em contato com o pesquisador responsável pelo projeto, nos telefones e endereço informados acima, para qualquer pergunta sobre meus direitos como participante. Declaro que recebi cópia do presente Termo de Consentimento.

Data: ___ /___ /____

____

Assinatura do Participante

____

Assinatura do Pesquisador Responsável

4.5 Supplement material

Sample size determined by Dipaola et. al 2016.
Pendulum-like recovery energy durring free walking, Pakinson's disease group x heathy control, during free walking.

[1] -- *Thursday, January 23, 2020 -- 00:45:15*
F tests - ANOVA: Repeated measures, within-between interaction
Analysis: A priori: Compute required sample size

Input:	Effect size f	=	0.58
	α err prob	=	0.05
	Power (1-β err prob)	=	0.95
	Number of groups	=	2
	Number of measurements	=	2
	Corr among rep measures	=	0.5
	Nonsphericity correction ε	=	1
Output:	Noncentrality parameter λ	=	16.1472000
	Critical F	=	4.9646027
	Numerator df	=	1.0000000
	Denominator df	=	10.0000000
	Total sample size	=	12
	Actual power	=	0.9505241

Sample size determined by Dipaola et. al 2016.
Forward mechanical work durring free walking, Pakinson's disease group x heathy control, during free walking.

[3] -- *Thursday, January 23, 2020 -- 09:29:20*
F tests - ANOVA: Repeated measures, within-between interaction
Analysis: A priori: Compute required sample size

Input:	Effect size f	=	0.11
	α err prob	=	0.05
	Power (1-β err prob)	=	0.80
	Number of groups	=	2
	Number of measurements	=	2
	Corr among rep measures	=	0.5
	Nonsphericity correction ε	=	1
Output:	Noncentrality parameter λ	=	8.0344000
	Critical F	=	3.8987868
	Numerator df	=	1.0000000
	Denominator df	=	164
	Total sample size	=	166
	Actual power	=	0.8045276

Sample size determined by Pellegrini et. al 2017
Pendulum-like recovery energy in heathy people free, walking vs Nordic walking

[5] -- *Thursday, January 23, 2020 -- 09:36:45*
F tests - ANOVA: Repeated measures, within-between interaction
Analysis: A priori: Compute required sample size

Input:	Effect size f	=	0.69
	α err prob	=	0.05
	Power (1-β err prob)	=	0.95
	Number of groups	=	2
	Number of measurements	=	2
	Corr among rep measures	=	0.5
	Nonsphericity correction ε	=	1
Output:	Noncentrality parameter λ	=	19.0440000
	Critical F	=	5.3176551
	Numerator df	=	1.0000000
	Denominator df	=	8.0000000
	Total sample size	=	10
	Actual power	=	0.9670432

Sample size determined by Pellegrini et. al 2017
External mechanical work in heathy people, free walking vs Nordic walking

[7] -- *Thursday, January 23, 2020 -- 09:38:58*
F tests - ANOVA: Repeated measures, within-between interaction
Analysis: A priori: Compute required sample size

Input:	Effect size f	=	0.24
	α err prob	=	0.05
	Power (1-β err prob)	=	0.80
	Number of groups	=	2
	Number of measurements	=	2
	Corr among rep measures	=	0.5
	Nonsphericity correction ε	=	1
Output:	Noncentrality parameter λ	=	8.7552000
	Critical F	=	4.1131653
	Numerator df	=	1.0000000
	Denominator df	=	36.0000000
	Total sample size	=	38
	Actual power	=	0.8210017

Sample size determined by Pellegrini et. al 2017
Forward mechanical work in heathy people, free walking vs nordic walking

[9] -- *Thursday, January 23, 2020 -- 09:40:22*
F tests - ANOVA: Repeated measures, within-between interaction
Analysis: A priori: Compute required sample size

Input:	Effect size f	=	0.66
	α err prob	=	0.05
	Power (1-β err prob)	=	0.95
	Number of groups	=	2
	Number of measurements	=	2
	Corr among rep measures	=	0.5
	Nonsphericity correction ε	=	1
Output:	Noncentrality parameter λ	=	17.4240000
	Critical F	=	5.3176551
	Numerator df	=	1.0000000
	Denominator df	=	8.0000000
	Total sample size	=	10
	Actual power	=	0.9532275

Sample size determined by Pellegrini et. al 2017
Vertical mechanical work in heathy people, free walking vs nordic walking

[10] -- *Thursday, January 23, 2020 -- 09:41:08*
F tests - ANOVA: Repeated measures, within-between interaction
Analysis: A priori: Compute required sample size

Input:	Effect size f	=	0.84
	α err prob	=	0.05
	Power (1-β err prob)	=	0.95
	Number of groups	=	2
	Number of measurements	=	2
	Corr among rep measures	=	0.5
	Nonsphericity correction ε	=	1
Output:	Noncentrality parameter λ	=	22.5792000
	Critical F	=	5.9873776
	Numerator df	=	1.0000000
	Denominator df	=	6.0000000
	Total sample size	=	8
	Actual power	=	0.9744918

Sample size determined by Pellegrini et. al 2017
step frequency in heathy people, free walking vs nordic walking

[12] -- *Thursday, January 23, 2020 -- 09:41:48*
F tests - ANOVA: Repeated measures, within-between interaction
Analysis: A priori: Compute required sample size

Input:	Effect size f	=	1.60
	α err prob	=	0.05
	Power (1-β err prob)	=	0.95
	Number of groups	=	2
	Number of measurements	=	5
	Corr among rep measures	=	0.5
	Nonsphericity correction ε	=	1
Output:	Noncentrality parameter λ	=	102.4
	Critical F	=	3.8378534
	Numerator df	=	4.0000000
	Denominator df	=	8.0000000
	Total sample size	=	4
	Actual power	=	0.9999953

4.6 Supplement material

Sample size determined by Sharifmoradi et al. 2016
Loading response peak force, Pakinson's disease group x heathy control, during free walking.

[1] -- *Wednesday, July 21, 2021 -- 10:55:09*
F tests - ANOVA: Repeated measures, within-between interaction
Analysis: A priori: Compute required sample size

Input:	Effect size f	= 0.57
	α err prob	= 0.05
	Power (1-β err prob)	= 0.9
	Number of groups	= 2
	Number of measurements	= 2
	Corr among rep measures	= 0.5
	Nonsphericity correction ε	= 1
Output:	Noncentrality parameter λ	= 15.5952000
	Critical F	= 4.9646027
	Numerator df	= 1.0000000
	Denominator df	= 10.0000000
	Total sample size	= 12
	Actual power	= 0.9439085

Sample size determined by Sharifmoradi et al. 2016
Terminal stance peak force, Pakinson's disease group x heathy control, during free walking.
.

[2] -- *Wednesday, July 21, 2021 -- 10:57:07*
F tests - ANOVA: Repeated measures, within-between interaction
Analysis: A priori: Compute required sample size

Input:	Effect size f	= 1.71
	α err prob	= 0.05
	Power (1-β err prob)	= 0.9
	Number of groups	= 2
	Number of measurements	= 2
	Corr among rep measures	= 0.5
	Nonsphericity correction ε	= 1
Output:	Noncentrality parameter λ	= 46.7856000
	Critical F	= 18.5128205
	Numerator df	= 1.0000000
	Denominator df	= 2.0000000
	Total sample size	= 4
	Actual power	= 0.9029075

Sample size determined by Sharifmoradi et al. 2016
Braking peak force, Pakinson's disease group x heathy control, during free walking.

[3] -- *Wednesday, July 21, 2021 -- 11:00:19*
F tests - ANOVA: Repeated measures, within-between interaction
Analysis: A priori: Compute required sample size

Input:	Effect size f	=	0.60
	α err prob	=	0.05
	Power (1-β err prob)	=	0.9
	Number of groups	=	2
	Number of measurements	=	2
	Corr among rep measures	=	0.5
	Nonsphericity correction ε	=	1
Output:	Noncentrality parameter λ	=	14.4000000
	Critical F	=	5.3176551
	Numerator df	=	1.0000000
	Denominator df	=	8.0000000
	Total sample size	=	10
	Actual power	=	0.9118353

Sample size determined by Sharifmoradi et al. 2016
Propulsive peak force, Pakinson's disease group x heathy control, during free walking.

[4] -- *Wednesday, July 21, 2021 -- 11:02:11*
F tests - ANOVA: Repeated measures, within-between interaction
Analysis: A priori: Compute required sample size

Input:	Effect size f	=	1.00
	α err prob	=	0.05
	Power (1-β err prob)	=	0.9
	Number of groups	=	2
	Number of measurements	=	2
	Corr among rep measures	=	0.5
	Nonsphericity correction ε	=	1
Output:	Noncentrality parameter λ	=	24.0000000
	Critical F	=	7.7086474
	Numerator df	=	1.0000000
	Denominator df	=	4.0000000
	Total sample size	=	6
	Actual power	=	0.9479378

Sample size determined by Alberto Encarnación-Martíneza et al. 2014
Loading response peak force, in heathy people free walking vs Nordic walking.

[5] -- *Wednesday, July 21, 2021 -- 11:04:03*
F tests - ANOVA: Repeated measures, within-between interaction
Analysis: A priori: Compute required sample size

Input:	Effect size f	=	0.715
	α err prob	=	0.05
	Power (1-β err prob)	=	0.9
	Number of groups	=	2
	Number of measurements	=	2
	Corr among rep measures	=	0.5
	Nonsphericity correction ε	=	1
Output:	Noncentrality parameter λ	=	16.3592000
	Critical F	=	5.9873776
	Numerator df	=	1.0000000
	Denominator df	=	6.0000000
	Total sample size	=	8
	Actual power	=	0.9173489

Sample size determined by Alberto Encarnación-Martíneza et al. 2014
Terminal stance peak force, in heathy people free walking vs Nordic walking.

[6] -- *Wednesday, July 21, 2021 -- 11:06:47*
F tests - ANOVA: Repeated measures, within-between interaction
Analysis: A priori: Compute required sample size

Input:	Effect size f	=	0.87
	α err prob	=	0.05
	Power (1-β err prob)	=	0.9
	Number of groups	=	2
	Number of measurements	=	2
	Corr among rep measures	=	0.5
	Nonsphericity correction ε	=	1
Output:	Noncentrality parameter λ	=	24.2208000
	Critical F	=	5.9873776
	Numerator df	=	1.0000000
	Denominator df	=	6.0000000
	Total sample size	=	8
	Actual power	=	0.9815051

Sample size determined by Alberto Encarnación-Martíneza et al. 2014
Braking peak force, in heathy people free walking vs Nordic walking.

[7] -- *Wednesday, July 21, 2021 -- 11:08:39*
F tests - ANOVA: Repeated measures, within-between interaction
Analysis: A priori: Compute required sample size

Input:	Effect size f	=	1.24
	α err prob	=	0.05
	Power (1-β err prob)	=	0.9
	Number of groups	=	2
	Number of measurements	=	2
	Corr among rep measures	=	0.5
	Nonsphericity correction ε	=	1
Output:	Noncentrality parameter λ	=	36.9024000
	Critical F	=	7.7086474
	Numerator df	=	1.0000000
	Denominator df	=	4.0000000
	Total sample size	=	6
	Actual power	=	0.9920993

Sample size determined by Alberto Encarnación-Martíneza et al. 2014
Propulsive peak force, in heathy people free walking vs Nordic walking.

[8] -- *Wednesday, July 21, 2021 -- 11:20:19*
F tests - ANOVA: Repeated measures, within-between interaction
Analysis: A priori: Compute required sample size

Input:	Effect size f	=	0.44
	α err prob	=	0.05
	Power (1-β err prob)	=	0.85
	Number of groups	=	2
	Number of measurements	=	2
	Corr among rep measures	=	0.5
	Nonsphericity correction ε	=	1
Output:	Noncentrality parameter λ	=	10.8416000
	Critical F	=	4.7472253
	Numerator df	=	1.0000000
	Denominator df	=	12.0000000
	Total sample size	=	14
	Actual power	=	0.8555024

4.7 Supplement material

FICHA DE ANAMNESE

Nome: ____ **Data de nasce.** ____/____/ ____

Estatura (m): ________ **Massa corporal (g):**______ **Idade:**______ **MMII (m)**________

Saudável ( ) **Parkinson** ( )

HY:______ **UPDRS**: ______ **Horário da medicação:** _______

Data da anamnese ____/____/_____ **IPAQ:** ________

Tempo de prática da Caminhada Nórdica (meses):__________

1. **Você foi submetido (a) à alguma cirurgia nos últimos 12 meses?**
   Sim ( ) Não ( )

2. **Você sofreu alguma lesão óssea nos últimos 12 meses?**
   Sim ( ) Não ( )

3. **Você sofreu alguma lesão óssea nos últimos 12 meses?**
   Sim ( ) Não ( )

4. **Você foi diagnosticado (a) com alguma doença cardiovascular nos últimos 12 meses?**
   Sim ( ) Não ( )

5. **Você foi diagnosticado (a) com alguma doença respiratória nos últimos 12 meses?**
   Sim ( ) Não ( )

6. **Você foi diagnosticado (a) com labirintite nos últimos 12 meses?**
   Sim ( ) Não ( )

7. **Você tem alguma incapacidade, que na sua opinião impeça de caminhar sem ajuda sobre uma passarela de madeira com e sem bastões?**

   Sim ( ) Não ( )

4.8 Supplement material

FICHA DOS TESTE DE CAMINHADA

Nome: ____ **Data de nasce.** ____/____/ _____

Data dia 1: ____/____/_____ **Saudável** ( ) **Parkinson** ( )

Horário da medicação: _______ **Horário início dos testes** _______

Modalidade: CN ( ) **CL** ( )						
Velocidades/Tempos						
N° Testes						
1.						
2.						
3.						
4.						
5.						
6.						
7.						
8.						
9.						
10.						

Data dia 2: ____/____/ ____**Horário da medicação:** _______ **Horário início dos testes** _______

Modalidade: CN ( ) **CL** ( )						
Velocidades/Tempos						
N° Testes						
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

4.9 Supplement material

ESCALA DE ESTADIAMENTO DE HOEHN E YAHR MODIFICADA

Estágio 0	Sem sinais da doença
Estágio 1	Doença unilateral
Estágio 1,5	Acometimento unilateral e axial
Estágio 2	Acometimento bilateral, sem prejuízo do equilíbrio
Estágio 2,5	Leve acometimento bilateral, recuperação no teste de equilíbrio (“*pull test*”)
Estágio 3	Acometimento leve a moderado; alguma instabilidade postural; independente fisicamente.
Estágio 4	Acometimento severo; ainda capaz de caminhar ou permanecer em pé sem auxílio.
Estágio 5	Usando cadeira de rodas ou acamado exceto se auxiliado.

5.0 Supplement material

ESCALA UNIFICADA DE AVALIAÇÃO PARA DOENÇA DE PARKINSON (UPDRS) - PARTE -III

Nome: ____ Data do dia: ____________
Observações:

Escala UPDRS (Parte III): Exame Motor
18. Fala
0. Normal.
1. Leve perda da expressão, dicção e/ou volume.
2. Monótona, inarticulada mas compreensível; moderadamente prejudicada.
3. Marcadamente prejudicada, difícil de compreender.
4. Ininteligível.

19. Expressão Facial
0. Normal.
1. Mínima hipomímia, podendo ser "face de pôquer".
2. Leve mas definida diminuição anormal da expressão facial.
3. Moderada hipomímia; lábios separados algumas vezes.
4. Facies em máscara ou fixa com severa ou completa perda da expressão facial; lábios separados mais de 0.5 cm.

20. Tremor de repouso
0. Ausente.
1. Leve e raramente presente.
2. Leve em amplitude e persistente. Ou moderado na amplitude, mas somente intermitentemente presente.
3. Moderada amplitude e presente a maior parte do tempo.
4. Marcada amplitude e presente a maior parte do tempo.

Face, lábios e queixo:
Mão direita:
Mão esquerda:
Pé direito:
Pé esquerdo:

21. Tremor postural e de ação das mãos
0. Ausente.
1. Leve, presente com a ação.
2. Moderado em amplitude, presente com a ação.
3. Moderado em amplitude, postural e de ação.
4. Marcado em amplitude, interferindo com a alimentação.
Direita:
Esquerda:

22. Rigidez *[movimento passivo das articulações maiores com o paciente relaxado em posição sentada, ignore a roda denteada]*
0. Ausente
1. Leve ou detectável só quando ativado por outros movimentos.
2. Leve a moderada.

3. Marcada, mas total extensão de movimentos obtida facilmente.
4. Severa, total extensão de movimentos obtida com dificuldade.
Pescoço:
Superior direita:
Superior esquerda:
Inferior direita:
Inferior esquerda:

23. "Finger Taps" *[paciente bate o polegar com o dedo indicador em rápida sucessão com a maior amplitude possível, cada mão separadamente]*
0. Normal
1. Um tanto quanto lento e/ ou reduzido na amplitude.
2. Moderadamente prejudicado. Cansaço definido e inicial. Pode apresentar pausas ocasionais durante o movimento.
3. Prejuízo severo. Freqüente hesitação ao iniciar o movimento ou pausas no movimento continuado.
4. Dificilmente pode executar a tarefa.
Direita:
Esquerda:

24. Movimentos manuais *[Paciente abre e fecha as mãos sucessivamente e rapidamente com a maior amplitude possível, cada mão separadamente]*
0. Normal
1. Levemente lento e/ ou reduzido na amplitude.
2. Moderadamente prejudicado. Cansaço nítido e inicial. Pode ter pausas ocasionais no movimento.
3. Prejuízo severo. Frequente hesitação ao iniciar movimentos ou pausas no movimento continuado.
4. Dificilmente pode executar a tarefa.
Direita:
Esquerda:

25. Movimentos rápidos alternantes das mãos *[movimentos de pronação-supinação das mãos, verticalmente ou horizontalmente, com a maior amplitude possível, cada mão separadamente]*
0. Normal
1. Levemente lento e/ ou reduzido na amplitude.
2. Moderadamente prejudicado. Cansaço nítido e inicial. Pode ter pausas ocasionais no movimento.
3. Prejuízo severo. Frequente hesitação ao iniciar movimentos ou pausas no movimento continuado.
4. Dificilmente pode executar a tarefa.
Direita:
Esquerda:

26. Agilidade das pernas *[paciente bate sucessivamente e rapidamente o calcanhar no chão, erguendo totalmente a perna. Amplitude deve ser aproximadamente de 8 cm].*
0. Normal.
1. Levemente lento e/ ou reduzido na amplitude.
2. Moderadamente prejudicado. Cansaço nítido e inicial. Pode ter pausas ocasionais no movimento.
3. Prejuízo severo. Frequente hesitação ao iniciar movimentos ou pausas no movimento continuado.
4. Dificilmente pode executar a tarefa.
Direita:
Esquerda:

27. Ao levantar-se da cadeira *[paciente tentando levantar de uma cadeira de metal ou madeira reta com os braços mantidos cruzados]*
0. Normal
1. Lento; ou pode necessitar mais que uma tentativa.
2. Impulsiona-se com os braços da cadeira.
3. Tende a cair para trás e pode ter que tentar mais que uma vez, mas pode levantar sem auxílio.

4. Sem capacidade de levantar sem auxílio.

28. Postura
0. Normalmente ereto.
1. Não fica totalmente ereto, postura levemente inclinada, poderia ser normal para pessoas mais idosas.
2. Coloca-se moderadamente inclinado, definidamente anormal; pode estar ligeiramente inclinado para um lado.
3. Postura severamente inclinada com cifose; pode estar moderadamente inclinado para um lado.
4. Marcada flexão com extrema anormalidade de postura.

29. Marcha
0. Normal
1. Caminha lentamente, pode ter marcha arrastada com passos curtos, mas sem festinação (acelerando os passos) ou propulsão.
2. Caminha com dificuldade, mas requer pouca ou nenhuma assistência; pode ter alguma festinação, passos curtos ou propulsão.
3. Severo distúrbio da marcha, necessitando auxílio.
4. Não pode caminhar, mesmo com auxílio.

30. Estabilidade Postural *[Resposta ao súbito deslocamento posterior produzido por puxada nos ombros enquanto o paciente está de pé com os olhos abertos e os pés ligeiramente separados. Paciente é preparado, podendo ser repetido algumas vezes a manobra]*
0. Normal
1. Retropulsão, mas volta à posição original sem auxílio.
2. Ausência de resposta postural, podendo cair se não for amparado pelo examinador.
3. Muito instável, tende a perder o equilíbrio espontaneamente.
4. Não consegue parar sem auxílio.

31. Bradicinesia e hipocinesias corporais *[Combinando lentificação, hesitação, diminuição do balanço dos braços, pequena amplitude, e pobreza dos movimentos em geral]*
0. Sem.
1. Mínima lentificação, dando ao movimento um caráter “deliberado”; poderia ser normal para algumas pessoas. Possivelmente amplitude reduzida.
2. Leve grau de lentificação e pobreza dos movimentos que é definitivamente anormal. Alternativamente, alguma redução da amplitude.
3. Moderada lentificação, pobreza ou diminuição da amplitude dos movimentos.
4. Marcada lentificação, pobreza ou diminuição da amplitude dos

5.1 Supplement material

QUESTIONÁRIO INTERNACIONAL DE ATIVIDADE FÍSICA – VERSÃO CURTA

Nome: ____

Data: ______/ _______ / ______ Idade: ______ Sexo: F ( ) M ( )

Nós estamos interessados em saber que tipos de atividade física as pessoas fazem como parte do seu dia a dia. Este projeto faz parte de um grande estudo que está sendo feito em diferentes países ao redor do mundo. Suas respostas nos ajudarão a entender que tão ativos nós somos em relação à pessoas de outros países. As perguntas estão relacionadas ao tempo que você gasta fazendo atividade física na **ÚLTIMA** semana. As perguntas incluem as atividades que você faz no trabalho, para ir de um lugar a outro, por lazer, por esporte, por exercício ou como parte das suas atividades em casa ou no jardim. Suas respostas são MUITO importantes. Por favor responda cada questão mesmo que considere que não seja ativo. Obrigado pela sua participação!

Para responder as questões lembre que:

- atividades físicas **VIGOROSAS** são aquelas que precisam de um grande esforço físico e que fazem respirar MUITO mais forte que o normal
- atividades físicas **MODERADAS** são aquelas que precisam de algum esforço físico e que fazem respirar UM POUCO mais forte que o normal

Para responder as perguntas pense somente nas atividades que você realiza **por pelo menos 10 minutos contínuos** de cada vez.

1a Em quantos dias da última semana você **CAMINHOU** <u>por pelo menos 10 minutos contínuos</u> em casa ou no trabalho, como forma de transporte para ir de um lugar para outro, por lazer, por prazer ou como forma de exercício?

dias _____ por **SEMANA** ( ) Nenhum

1b Nos dias em que você caminhou <u>por pelo menos 10 minutos contínuos</u> quanto tempo no total você gastou caminhando **<u>por dia</u>**?

horas: ______ Minutos: _____

2a Em quantos dias da última semana, você realizou atividades **MODERADAS** por pelo menos 10 minutos contínuos, como por exemplo pedalar leve na bicicleta, nadar, dançar, fazer ginástica aeróbica leve, jogar vôlei recreativo, carregar pesos leves, fazer serviços domésticos na casa, no quintal ou no jardim como varrer, aspirar, cuidar do jardim, ou qualquer atividade que fez aumentar **moderadamente** sua respiração ou batimentos do coração **(POR FAVOR NÃO INCLUA CAMINHADA)**

dias _____ por **SEMANA** ( ) Nenhum

2b Nos dias em que você fez essas atividades moderadas por pelo menos 10 minutos contínuos, quanto tempo no total você gastou fazendo essas atividades **por dia**?

horas: ______ Minutos: _____

3a Em quantos dias da última semana, você realizou atividades **VIGOROSAS** por pelo menos 10 minutos contínuos, como por exemplo correr, fazer ginástica aeróbica, jogar futebol, pedalar rápido na bicicleta, jogar basquete, fazer serviços domésticos pesados em casa, no quintal ou cavoucar no jardim, carregar pesos elevados ou qualquer atividade que fez aumentar **MUITO** sua respiração ou batimentos do coração.

dias _____ por **SEMANA** ( ) Nenhum

3b Nos dias em que você fez essas atividades vigorosas por pelo menos 10 minutos contínuos quanto tempo no total você gastou fazendo essas atividades **por dia**?

horas: ______ Minutos: _____

Estas últimas questões são sobre o tempo que você permanece sentado todo dia, no trabalho, na escola ou faculdade, em casa e durante seu tempo livre. Isto inclui o tempo sentado estudando, sentado enquanto descansa, fazendo lição de casa visitando um amigo, lendo, sentado ou deitado assistindo TV. Não inclua o tempo gasto sentando durante o transporte em ônibus, trem, metrô ou carro.

4a Quanto tempo no total você gasta sentado durante um **dia de semana**?

______horas ____minutos

4b Quanto tempo no total você gasta sentado durante em um **dia de final de semana**? ______horas ____minutos

CHAPTER 5

5.1 The published studies during master's degree

5.1.1 Abastract presented

LEAL-NASCIMENTO, A. H; ZANARDI, A.P.J.; SILVA, E.S.; AIRES, A. BAPTISTA, R. R.; PEYRÉ-TARTARUGA, L. A. Mecanismo pendular e Caminhada nórdica: estudo piloto. **II Symposium on Physiomechanics of Terrestrial Locomotion,** 2019, Florianópolis - SC.

LEAL-NASCIMENTO, A. H; SILVA, E.S; ZANARDI, A.P.J.; BAPTISTA, R. R.; PEYRÉ-TARTARUGA, L. A. Analysis of Nordic walking poles on self-selected walking speed in people with Parkinson's disease. **XVIII Brazilian Congress of Sport and Exercise Psychology and XI International Congress of Sport and Exercise Psychology,** 2020, Recife - PE.

5.1.2 Submitted abstracts

PEYRÉ-TARTARUGA, L. A; BAPTISTA, R. R; IVANISKI-MELLO. A; SILVA, E.S; LEAL-NASCIMENTO, A. H. An analytical approach to the understanding of GRF generation during human walking. **26th Annual Virtual Congress of the European College of Sports Science,** 2021.

LEAL-NASCIMENTO, A. H; SILVA, E.S; ZANARDI, A.P.J.; IVANISKI-MELLO. A; PASSOS MONTEIRO, E; CARVALHO, A R.; ARDIGÒ, L. P.; BAPTISTA, R. R.; PEYRÉ-TARTARUGA, L. A. Nordic walking and running in Parkinson's disease: kinetic and spatiotemporal responses. **XIX Brazilian Congress of Biomechanics, XI Neuromechanics Symposium and III Latin American Meeting of Biomechanics,** 2021, virtual – Belo Horizonte.

LEAL-NASCIMENTO, A. H; SILVA, E.S; ZANARDI, A.P.J.; IVANISKI-MELLO. A; PASSOS MONTEIRO, E; CARVALHO, A R.; BAPTISTA, R. R.; PEYRÉ-TARTARUGA, L. A. Walking with poles in people with Parkinson's disease: pendulum energy recovery and mechanical work. **XIX Brazilian Congress of Biomechanics, XI Neuromechanics Symposium and III Latin American Meeting of Biomechanics,** 2021, virtual – Belo Horizonte.