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# Nordic walking and arm swing asymmetry in people with Parkinson's disease: protocol for a randomised clinical trial

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## ABSTRACT

People with Parkinson's disease (PD) face disruptions in arm swing (AS) motion during walking, including a reduction in amplitude and an increase in asymmetry. Both conditions are detrimental to gait performance. Nordic walking (NW) is a walking modality that uses poles and can positively affect the parameters of AS. This study aims to compare an NW with a free walking (FW) protocol and investigate its effects on AS asymmetry, AS amplitude and gait parameters in people with PD. Twenty-eight people with PD, stages 1–3 on the Hoehn and Yahr Scale, will be randomly assigned to the NW training group (n=14) or the FW training group (n=14). The primary outcomes are amplitude asymmetry of AS (%) and AS amplitude (deg). We will also analyse temporospatial measurements during walking, functional mobility and quality of life. Blinded researchers will conduct evaluations at baseline (T0), postintervention (T1) and at 1 month follow-up (T2). Participants will complete 24 supervised NW or FW training sessions for 12 weeks. This is the first study to address the effects of NW on the asymmetry of AS, AS amplitude and its influence on gait parameters. We hypothesise that an NW programme in PD will reduce the asymmetry and increase the AS amplitude during gait to a greater extent than FW. The results of this study may provide new evidence to understand the effects of NW on gait in people with PD. The study was registered in ClinicalTrial.gov (NCT06342271).

### WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ People with Parkinson's disease (PD) have greater arm swing (AS) asymmetry and lower amplitude, and these alterations affect gait performance and increase the risk of falling.

⇒ Nordic walking (NW) is a sport consisting of walking using two poles. Therefore, it can positively affect the parameters of AS and gait performance to a greater extent than free walking (FW).

### WHAT THIS STUDY ADDS

⇒ This is the first study to address the effects of NW on the asymmetry and amplitude of AS and its influence on temporospatial gait parameters.

⇒ The results of this study may provide new evidence to understand the effects of NW on gait in people with PD in comparison to FW.

### HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ We highlight the importance of upper limb performance during locomotion in people with PD and the study of new rehabilitation strategies which is limited in the literature and clinical practice.

⇒ This study provides a detailed protocol of NW training for clinicians working with people with PD, which will allow replication of our clinical trial if NW is an effective intervention.

## INTRODUCTION

Parkinson's disease (PD) is a chronic neurodegenerative disorder and one of the leading causes of disability.[1] Gait disturbances are frequent in PD and strongly related to falls, dependency and low quality of life.[2 3] Changes in lower limbs' gait parameters are widely studied in PD.[4] However, the literature does not address the gait kinematic parameters of upper limbs.

According to a recently published meta-analysis, people with PD present lower arm swing (AS) amplitude and velocity, and greater asymmetry during gait compared with healthy peers.[5] These changes are considered early features of PD,[6] and an independent predictor of falls.[7] During locomotion, movements of the upper and lower limbs influence each other.[8] When these movements are asymmetrical, it implies a higher energy cost and a greater probability of developing freezing of gait.[9] Improvements in AS parameters would contribute to decreased angular momentum around vertical and vertical ground reaction moment caused by the rotation of the whole body on the vertical axis, increasing the

walking speed and step length, promoting stability, and decreasing energy costs during walking.[8 10 11]

Nordic walking (NW) is considered an outdoor sport modality, consisting of walking rhythmically using two poles. NW technique has shown that the sequence of active movements demands mechanically and energetically both the upper and lower limbs during walking, unlike other strategies such as free walking (FW) or treadmill walking.[12 13] In addition, using the poles rhythmically could promote mid-lateral stability and act as an external sensory signal, optimising intersegmental coordination and temporal organisation of gait.[14] No studies have evaluated the effects of NW on the kinematic parameters of AS. Considering that NW favours the active use of the upper limbs during walking, we hypothesise that a NW training programme in PD will reduce the asymmetry and increase the AS amplitude during gait to a greater extent than FW. On the other hand, improvements in AS could positively influence the performance of lower limbs during walking, increasing gait speed, step length, functional mobility and quality of life.

## MATERIAL AND METHODS

### Study design

This protocol is for a randomised controlled clinical trial, 1:1, parallel, single-blinded (evaluators), of superiority, conducted according to the recommendations of Standard Protocol Items for Clinical Trials 2013.[15]

### Study setting

The study will be conducted in the Laboratory of Human Movement Sciences, athletic track and trails of the University of Talca, Chile.

### Participants

People with PD belong to PD groups, community rehabilitation centres and/or the Physical Therapy Clinic of the University of Talca, Talca, Chile. Table 1 shows the inclusion and exclusion criteria.

### Sample size calculation

The sample size was calculated using G*Power V.3.1.9.4 software, accepting an alpha risk of 0.05 and a beta risk of 0.2 for a one-sided contrast. A minimum of 22 participants will be required considering the difference in AS amplitude in people with PD (0.2 m±0.08 m) compared with people without PD (0.29±0.08 m) with an effect size of 1.125.[16] Considering a loss of 20%, 28 participants will be included (14 in the NW group and 14 in the FW group).

### Recruitment, randomisation, blinding and treatment allocation

Groups of people with PD who attend the community rehabilitation centres and/or the Physical Therapy Clinic of the University of Talca, Chile, will be invited to participate through posters disseminating the research, explaining the mechanisms for contacting the principal investigator. Each interested person will be contacted by telephone. All the information and explanation of the study's nature, purpose and procedure will be delivered, as well as any inconveniences and risks of participation. A date will be agreed on to explain, read and sign the informed consent form before their inclusion in the study. Subsequently, to verify the inclusion and exclusion criteria, a brief general health questionnaire will be completed, the Hoehn and Yahr (H&Y) Scale will be applied to establish the stage of the disease,[17] and to assess cognitive status, Montreal Cognitive Assessment will be applied.[18] All information reported by participants will be corroborated by medical records or the participant's physician.

Those meeting the selection criteria will be invited to the Human Movement Sciences Laboratory of the University of Talca to conduct baseline evaluations.

After the baseline evaluation, an assistant (R2) who will not participate in the evaluations, intervention, or data analysis will assign a number to each participant and perform a randomisation process into blocks of four participants to assign them to study groups using a digital

**Table 1** Inclusion and exclusion criteria

| | |
|---|---|
| Inclusion criteria | ► Diagnosis of idiopathic Parkinson's disease (PD), confirmed by a neurologist following the criteria of the Parkinson's Disease Society Brain Bank criteria<br>► Age 50–80 years<br>► Disease stage between I and III according to Hoehn and Yahr Scale (H&Y Scale)<br>► Able to walk without technical aids |
| Exclusion criteria | ► Cognitive impairment (score <26 in the Montreal Cognitive Assessment (MoCA))<br>► Surgery less than 3 months or deep brain stimulation (DBS)<br>► Any comorbidity that has a contraindication to moderate-to-high physical exercise intensity<br>► Participate in any walking training two or more times per week<br>► Diagnosis of any other neurological or musculoskeletal condition that can cause motor compromise and interfere with locomotion |

Note: All information will be obtained through medical history reported by participants and corroborated by medical records or the participant's physician.

research randomiser (https://www.random.org). Participants will be allocated to the intervention group with NW or the intervention group with FW, with a 1:1 allocation ratio, matched by disease stage according to H&Y Scale (stages I, II and III). The distribution will be blinded to the evaluators (R3, R4) and statisticians (R5).

## Interventions

The lack of standardised protocols for NW prescription has made it difficult to compare different studies. Based on this, the framework for NW exercise prescription for PD will be used.[19]

The NW training will be supervised by a physiotherapist instructor from the Chilean School of Nordic Walking Fittrek, Chile (R6). A physiotherapist will carry out the FW programme (R7). Patients will be asked to abstain from engaging in a direct physical therapy programme that involves therapeutic gait training during the intervention and follow-up periods.

The training will be developed in the athletics track and trails of the University of Talca, Chile, with a demarcation of 400 m to control the distance travelled in each training. The participants will be trained in groups (NW or FW) on alternate days in the morning, according to the peak of action of the pharmacological treatment, that is, between 30 min and 2 hours after ingesting the medication, which will be recorded in each session.

The extension for both groups will be 12 weeks, two times a week on alternate days, completing 24 1-hour sessions. The NW group will carry out the first four induction sessions to the technique. The FW group will complete the same number of sessions. The first four sessions will be an induction to gait training (details of the induction phase for both groups are given in online supplemental table S1).

The training sessions will be organised in three phases: (1) Warm-up phase, (2) Training phase and (3) Calm-down phase. The general structure of the training sessions is described in table 2.

The protocol will be standardised for both the groups. The training phase differs from the NW programme in that poles are used during training. The poles will be telescopic, made of aluminium, with a cork handle and removable strap, a flexible hard metal tip and height adjustment between 100 cm and 125 cm, and a weight not exceeding 380 g.

The NW programme was closely monitored for each participant, continuously assessing gait pattern, NW technique and exercise response during training.

The NW technique will be controlled in each session by checking four critical elements according to the Fittrek standard power technique:[20] correct posture when walking, coordinated steps, pendulum movement of the arms from the shoulder, and effective push of the poles from the moment of nailing until reaching hip height with the hand. In addition, releasing and recovering the pole will be encouraged once the hand passes over the hip during walking. The trainer will focus on promoting the amplitude of the stride and the AS without losing the naturalness of the gait in a rhythmic and coordinated way, increasing the speed when walking. Errors will be corrected session by session, such as decreased width of the AS and step, height adjustment of the pole to facilitate AS, vertical support of the poles and forward support, tendency to drag the tips of the poles, overload of the arm extensor, lack of waist dissociation and lack of coordination. In the case of technical errors, the progression will be re-started with technique induction exercises, and their correction will be checked (online supplemental table S1). Trainers will review the aims with participants weekly and provide direct augmentative feedback on the results achieved regarding walking speed and distances covered session by session (knowledge of results). On the other hand, they will also receive feedback regarding the quality of the NW or FW technique (knowledge of execution). Learning will be facilitated through modelling, visual feedback via video, visual cues and verbal attention instruction. The trainers will review the objectives with participants weekly. The work intensity for both groups will be between 60% and 80% of the reserve heart rate and in a range between 11 and 15 of the Borg Perception of Effort Scale. To monitor the training intensity, a Polar Ft1 brand heart rate monitor will be placed on the thorax at the xiphoid process level. Gait intensity

**Table 2** The general structure of the training sessions

| Phase | Time (min) | Description |
|---|---|---|
| Warm-up phase | 5–10 | General joint mobility exercises, progressive walking exercises in place, FW at a comfortable speed and in different directions |
| Training phase | 40–50 | NW or FW, at intervals, progressing to a continuous walk on varying terrains (grass, gravel, land) |
| Calm-down phase | 5–10 | Muscle stretching and breathing exercises. |

FW, free walking; NW, Nordic walking.

will also be modulated by perceived gait speed, using the following descriptors: comfortable: self-selected gait speed; intermediate: between comfortable speed and maximum speed; fast: maximum walking speed; maxima: maximum trot. Training will progress according to the Peyré-Tartaruga proposal, 2022,[19] which considers a systematic increase in the walk duration, speed and intensity. The details of the training prescription for both familiarisation and training of NW and FW are presented in online supplemental table S2.

### Outcome measures

Two physiotherapists (R3-R4), blinded to the study groups, will conduct the evaluations at T0 (baseline assessment), T1 (after 12 weeks of intervention) and T2 (1 month follow-up). Participants will be evaluated in the morning, between 30 min and 2 hours after taking the medication, during the 'ON' phase. Outcome measures will be administered using standardised procedures and the same testing order at all time points. Baseline assessments to characterise the sample and prescribe training are described in online supplemental material

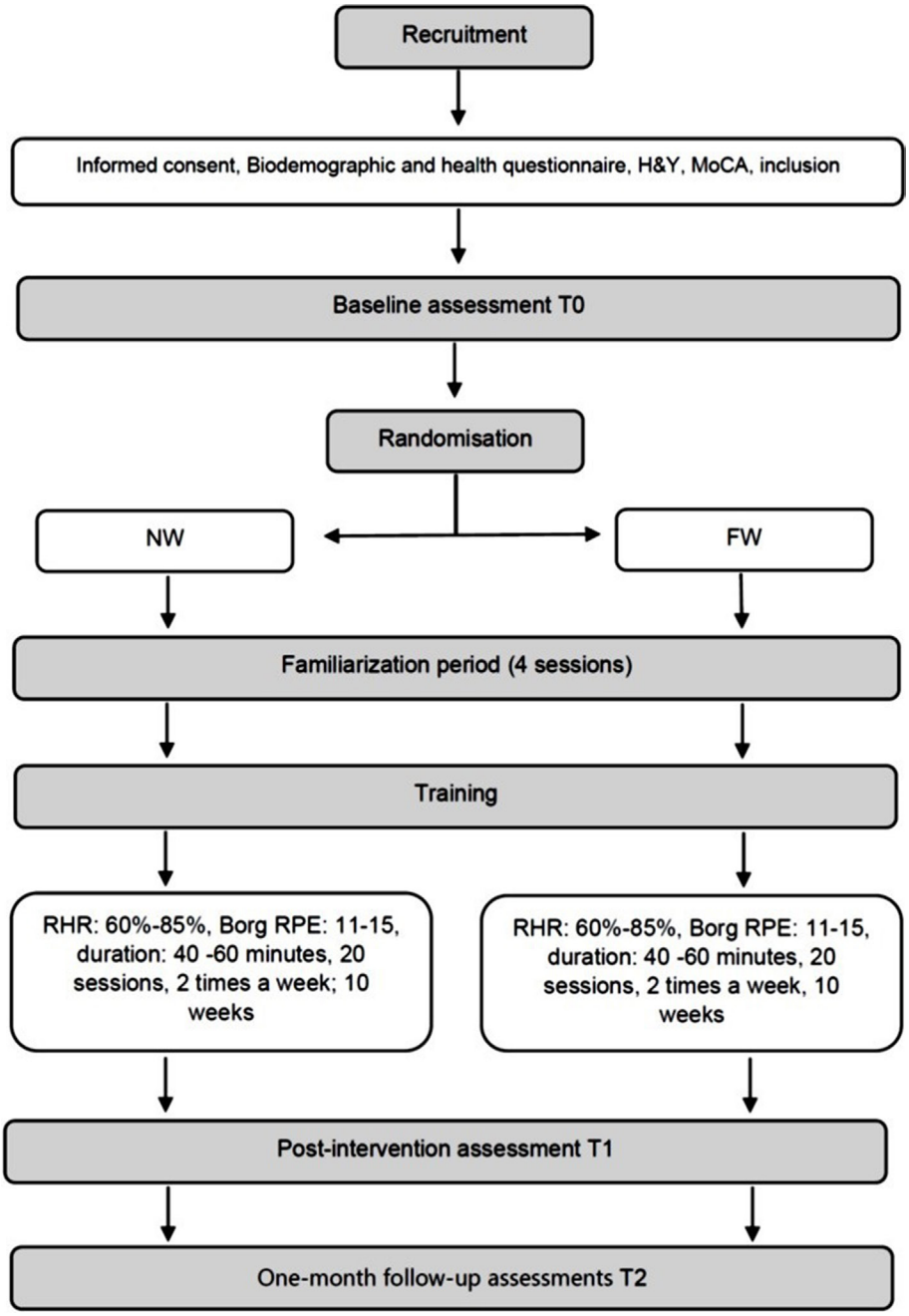


**Figure 1** Trial flow chart. FW, free walking; H&Y, Hoehn and Yahr; MoCA, Montreal Cognitive Assessment; NW, Nordic walking; RHR, reserve heart rate; RPE, rate of perceived exertion.

3. Evaluations will be divided into 2 days to avoid fatigue (figure 1).

Primary outcomes are the amplitude of the AS (range of motion) (deg) and asymmetry of the amplitude of AS between left and right swings (0% means no asymmetry) (%) during walking.

Secondary outcomes are temporospatial measurements during walking: gait speed (m/s), step length (m), functional mobility and quality of life.

### Kinematic of the AS during walking

The AS parameters will be acquired through 2 Trigno inertial measurement unit (IMU) sensors (Delsys Inc., Boston, Massachusetts, USA), placed at wrist level, fixed with a semielastic velcro strap 30 mm above the styloid, and oriented according to right-handed coordinate systems (x forward, y left and z vertical). The sensors have a triaxial accelerometer (max outputs±16 g), a triaxial gyroscope (max outputs±2000°/s) and a magnetometer (10 Hz). Data capture will be performed at a 148 Hz sampling rate on both IMUs synchronised in the same time window with EMGWorks V.4.3.1 acquisition software (Delsys, Boston, Massachusetts, USA).

Each participant will walk through an 8 m long and 3 m wide corridor, free of obstacles, in comfortable shoes at a self-selected preferred speed. Three repetitions will be performed, stopping at each end for 3 s and then turning.[21] The variables will be analysed between 2 m and 6 m of the corridor to avoid the influence of acceleration and deceleration on the walk. Participants will be accompanied and can rest at the end of the corridor if necessary.

AS is defined as a rotational arm movement occurring during walking and running in bipeds with a periodicity of 1–2 Hz and in opposite directions (anterior and posterior). The hand and arm move freely through space in opposite directions, with most of the movement occurring in the sagittal plane of the body frame.[22] The AS parameters will be extracted with a validated AS algorithm for both upper limbs, with a periodicity between 0.3 Hz and 3 Hz and a minimum amplitude of 5°.[22] Only rotations around the frontal and sagittal axes will be considered because body turns can influence longitudinal rotations.

To determine the AS of each member, only the gyroscope functions (gross angular velocity of the three axes of the IMU) and the capture frequency will be configured[23] and exported in txt format for its postprocessing in Matlab 2017a. The gyroscope data will be filtered with a second order Butterworth low pass filter with a cut-off frequency of 3 Hz to omit noise and possible filter from the obtained signal.

The AS asymmetry will be determined according to the arms symmetry index (ASI) considering the phases with oscillation detected in both arms simultaneously with the following equation: $ASI = ((L–R) / \max(L, R)) \times 100$; where L will correspond to the amplitude or peak of the angular velocity of the left arm and R to the right arm. An ASI of 0% will be considered to determine an identical symmetry between the left and right arms.[22]

### Temporospatial measures during walking

Gait temporospatial parameters (gait speed and step length) will be acquired under the same test conditions and simultaneously to obtain the AS parameters using a wireless IMU sensor model G-walk® (BTS Bioengineering, Milan, Italy) fixed with a semielastic belt between the fifth lumbar and second sacral vertebrae. Data will be recorded using the G-Studio software (BTS Bioengineering, Milan, Italy) at a capture frequency of 100 Hz and transmitted via Bluetooth to a computer. Data processing will be done through a specific software (BTS G-Studio) that is validated in different populations.[24]

### Functional mobility

Functional mobility will be measured through the Timed Up and Go test. The test measures the function of the lower limbs, mobility and risk of falling. The participant will be instructed to get up from a chair (without using their arms), walk to a mark 3 m away, turn around and sit back in the chair. The time in seconds it takes to complete the circuit if the time is greater than 11 s, indicates a risk of falling.[25]

### Quality of life

Quality of life will be assessed through the Parkinson's Disease Questionnaire. This instrument is composed of 39 questions divided into eight domains related to quality of life. Each item can be answered according to five predetermined responses (never, rarely, sometimes, frequently and always). The score ranges from 0 to 4 points, and the total ranges from 0 to 100. A lower score reflects a better quality of life. The instrument has been validated for the Spanish version.[26]

### Other outcomes

Adherence will be monitored by recording attendance at training sessions. Fully adherent participants will be considered those who attend more than 80% of the training programme sessions. To promote adherence, if a participant is absent for two sessions without justification, they will be contacted by telephone to record the reasons for the absence and to motivate them to return if possible.

### Data management

The participants' data obtained both in the recruitment and evaluation and follow-up will be compiled and stored in a single computer destined for the study, which will have restricted access with a password only to the principal investigator (JE-A) and a co-responsible person (CC-M). The informed consent form will be filed and stored in a filing cabinet, to which only the investigators responsible and co-responsible for the trial will have access. The information and records of each participant will be extracted in a data form in which an identifier number will be used to protect the confidentiality of

the participant in the analysis and review of data. The principal investigator (JE-A) and a co-responsible person (CC-M) will be the custodians of the documentation, which will be stored for 5 years. The quality control of the data and records will be the responsibility of the principal investigator and the co-responsible person, who will verify that the data were correctly extracted and are suitable for further analysis.

### Statistical analysis

The statistical package SPSS V.25 (Chicago, Illinois, USA) and the statistical package GraphPad Prism V.8 (San Diego, California, USA) will be used. Descriptive data analysis will be calculated for all variables in both groups at baseline (T0). The Shapiro-Wilk test will verify the normality distribution for each continuous variable. Levene's test of homogeneity of variance will be used to assess the effects of the randomisation procedure. To investigate differences in AS parameters, a repeated measures analysis of variance will be performed with two factors (time × group) to test the differences in the effect of two intervention protocols in times (T0), postintervention (T1) and a follow-up 1 month after the intervention (T2). To determine intragroup and intergroup differences, a Bonferroni post hoc test will be applied. Pearson's correlation coefficient will be used to estimate the relationship between kinematic parameters and asymmetry of AS with lower limb parameters. Subsequently, a multiple regression analysis will be performed.

In the case of a non-normal distribution, data will be presented as the median and IQR, and non-parametrical tests will be used. A comparison of adverse effects between the two groups will be made using the $\chi^2$ test. An imputation method using regression will be used to treat absent longitudinal data (missing data). All results with a value of $p<0.05$ will be considered statistically significant. Additionally, the effect size will be obtained with Cohen's d test. The following standards will be used to interpret the results: Cohen <0.2 is considered a trivial effect; 0.2–0.5 is a small effect; 0.5–0.8 is a moderate effect; and >0.8 is a large effect.

### Data monitoring

This study will be supervised by a doctoral thesis committee of two members. The main author must present the study design to the committee before starting the enrolment of the participants.

### Adverse events

Adverse events (AEs) have deleterious or unfavourable results that occur during the evaluation or before, during or after exercise, such as nausea, headache, falls, and disabling pain. AEs and those unrelated to the intervention (such as exacerbating pre-existing diseases or worsening PD symptoms) will be monitored in each session and reported in the results. In case the patient or physiotherapist notices AEs that require medical attention, the physiotherapist will apply a care protocol and inform the principal investigator, who will collect a complete description of the event on a form designed for that. The intervention will be interrupted if the AE makes it impossible for the participant to perform physical exercise. The reasons will be explained, and all the necessary guidance and accompaniment will be given to attend a medical check-up at the care centre. In addition, the information and records obtained in the different evaluations will be permanently and irretrievably removed from the databases to maintain the confidentiality of the participants. Therefore, they will not be considered in the subsequent analysis.

### Audit and inspections

The data and documents will be accessible to auditors from the Scientific Ethics Committee of the University of Talca, Talca, Chile. The Principal Investigator will answer questions during inspections. All parties involved will keep the participants' data confidential.

## DISCUSSION

NW is a physical exercise modality that can be used as a non-pharmacological strategy to reduce functional decline in people with PD. Some studies have reported the effects of NW on motor and non-motor symptoms,[27] functional mobility,[28 29] quality of life,[30] balance,[31] and walking in PD.[27 29] NW seems to be superior to FW for improving locomotion and quality of life. However, a recent systematic review highlighted the high heterogeneity of the studies regarding methodological quality, selection criteria, training prescription and comparison groups, making it very difficult to replicate their results.[32]

Our study protocol provides a structured programme that follows the recommendations for evaluating and intervening with NW in people with PD.[19] Both training programmes (NW and FW) are identical in intensity, volume and duration. Also, we considered all the critical elements for exercise prescription, such as specificity, overload, individualisation and progression. In our protocol, the NW group participants will be familiarised using poles. Both groups will be assessed at a 1-month follow-up, and we will register any AEs. These are aspects that have, sometimes, not been considered in previous trials.

We highlight the importance of investigating the upper limb parameters during locomotion in people with PD. The decrease in AS and its asymmetry are prevalent dysfunctions and influence the performance of the lower limbs while walking. The increase in the AS amplitude increases cadence, gait speed and stride length.[8 10] NW differs from FW by using poles, favouring upper limb activity. We hypothesise that NW can increase AS amplitude, reduce asymmetry and positively influence gait parameters. Previous studies have shown that NW improves spatiotemporal gait parameters and ground reaction force compared with FW in healthy subjects[33] and self-selected gait speed in people with PD to a greater extent than FW.[28] The literature argues that these effects may result from using poles. However, this relationship has yet to be demonstrated.

To our knowledge, this is the first study to address the effects of NW on the kinematics parameters of AS and its influence on temporospatial gait parameters. However, this study may have some limitations. For example, the extent of the sensorimotor compromise of some participants, such as bradykinesia, rigidity and incoordination, may prevent the correct execution of the NW technique. To overcome this limitation, our protocol will include people with mild-to-moderate compromise, and we will ensure a period of NW familiarisation to acquire the correct technique. This study provides a detailed protocol to clinicians that will allow for the reproduction of our clinical trial results.

## RESEARCH ETHICS AND DISSEMINATION

The study processes will follow the study protocol, and any protocol amendments will be submitted to the University of Talca-Chile Ethics Committee.

Once the results are available, they will be communicated to the participants. It is planned to participate in professional meetings and congresses, and to publish this protocol and the trial results in scientific journals. The identity of the participants will never be included.

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**Competing interests** None declared.

**Patient and public involvement** Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

**Patient consent for publication** Not applicable.

**Ethics approval** This study involves human participants and was approved by the Ethics Committee of the University of Talca-Chile (Folio 24/2024). Participants gave informed consent to participate in the study before taking part.

**Provenance and peer review** Not commissioned; externally peer reviewed.

**Data availability statement** Data sharing is not applicable as no data sets were generated and/or analysed for this study.



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