NeuroRehabilitation 44 (2019) 433–443
DOI:10.3233/NRE-182638
IOS Press

Acute kinematic and neurophysiological effects of treadmill and overground walking in Parkinson's disease

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Abstract.
BACKGROUND: The use of the treadmill as a gait rehabilitation tool has provided novel options for treatment of gait impairments in Parkinson's Disease (PD). However, the neural mechanisms underlying these therapeutic effects in PD remain unknown and whether any therapeutic effects from treadmill training can be reproduced on overground walking.
OBJECTIVE: To examine the immediate short-term effects of a single session of treadmill and overground walking on gait, spinal and corticospinal parameters in PD.
METHODS: PD participants (N = 15) were evaluated in two separate sessions under two walking conditions: walking over a treadmill and walking overground. Overground walking performance, the Soleus H-reflex, Reciprocal Ia-Inhibition, Intracortical Facilitation (ICF) and Short Intracortical Inhibition (SICI), were evaluated before and after each condition.
RESULTS: Gait speed and stride length improved in post-treadmill compared with pre-treadmill. No significant changes in these gait parameters were found for the pre vs. post-overground condition. ICF values and Hmax/Mmax ratio decreased after, compared with before, the two walking conditions.
CONCLUSIONS: Treadmill walking, but not overground walking, lead to an improvement in the stride length and gait speed in the PD patients without evidence of different modulation on spinal and corticospinal parameters.

Keywords: Parkinson's disease, rehabilitation, gait, transcranial magnetic stimulation, H-reflex

1. Introduction

Gait disturbances are one of the principal and most incapacitating symptoms of Parkinson's disease (PD) (Keus, Munneke, Nijkrake, Kwakkel, & Bloem, 2009). PD gait is characterized by the inability to regulate an appropriate stride length, a reduced gait speed and an increased stride-to-stride variability. Gait disorders in PD may also include festination, start hesitation during gait initiation, freezing of gait and falls (Ebersbach, Moreau, Gandor, Defebvre, & Devos, 2013). In spite of this, the neurophysiology of gait has not been extensively studied in people with PD, which hinders the targeting of successful treatment strategies. Hiraoka et al. (2006) suggested that PD subjects show an inhibited Soleus H-reflex during gait initiation (Hiraoka, Matsuo, & Abe, 2005).

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This H-reflex inhibition is removed after deep brain stimulation of the pedunculopontine nucleus (Mariangela Pierantozzi et al., 2008), suggesting a role of this reflex in the gait impairments in PD. Others studies have reported a reduction of reciprocal Ia-inhibition at the onset of a voluntary ankle dorsiflexion, a finding attributed to abnormal corticospinal control of Ia inhibitory interneurons during movement and that was correlated with the motor part of the unified Parkinson's disease rating scale (Hayashi et al., 1988; Morita et al., 2002). In addition, a Transcranial Magnetic Stimulation (TMS) study revealed abnormalities in intracortical facilitation (ICF) of the lower limb motor cortex, while no changes were found for short intracortical inhibition (SICI), that may be related with the decreased stride length and the slower gait speed in PD (Vacherot, Attarian, Vaugoyeau, & Azulay, 2010).

In the last decade, there has been an increased interest in the treadmill as a potential gait rehabilitation tool in PD. Several studies have shown that treadmill training enlarge stride length, increase gait speed, decrease double support and reduce gait variability in PD subjects (Bello, 2013; Bello, Marquez, Camblor, & Fernandez-Del-Olmo, 2010; Miyai et al., 2000, 2002). The effects of several sessions of treadmill walking could result from the gait benefits observed immediately after a single session of treadmill walking. For example, after walking on a treadmill for 20 minutes, PD patients were able to walk overground with lower stride-to-stride variability (Frenkel-Toledo et al., 2005) and longer stride length (Fernández-Lago et al., 2015). Although, these short-term gait improvements were attributed to the treadmill walking, the studies did not examine whether these effects could also be achieved by a single session of overground walking. This is of relevance in order to determine whether the treadmill has a specific therapeutic effect in PD.

In spite of the beneficial effects associated with the use of a treadmill in PD, the mechanisms underlying these improvements still remain unknown, even though several hypotheses have been suggested (Bello & Fernandez-Del-Olmo, 2012). One of these theories refers to the external rhythmical cues. It is well known that people with PD can improve their gait pattern in the presence of regulatory sensory stimulation, such as with visual and auditory cues (Morris, Iansek, Matyas, & Summers, 1996). Therefore, it is possible that the belt displacement at a constant speed, enhance the lower limb movements and providing adequate proprioceptive inputs (repeated contraction and relaxation of muscle groups). These proprioceptive inputs could act as an external rhythmical cue, bypassing the defective pallidocortical projections, resulting in a normalized gait pattern in individuals with PD (Bello et al., 2010). In addition, the proprioceptive inputs could stimulate the Central Pattern Generators (CPG), that refers to locomotor neural circuits at spinal level, that can produce rhythmic movements (Duysens & Crommert, 1998). Nevertheless, there are no studies that explored the neurophysiological effects of treadmill walking in PD.

Consequently, the aim of the current study was to explore the immediate effects of a single session of either treadmill or overground walking on gait, spinal and corticospinal measurements in PD. We hypothesized that only the treadmill walking session would lead to an improvement in the gait kinematics in PD subjects, as well as walking-related neurophysiological modulations.

2. Methods

2.1. Study design

The present study consists on a pilot study with a quasi-experiment design, in order to explore the short-term neurophysiologic effects of a single session of treadmill in comparison with overground walking in PD patients.

2.2. Subjects

Fifteen individuals, diagnosed with idiopathic PD by a neurologist according to the United Kingdom Bank Criteria (Hughes AJ, Daniel SE, Kilford L, 1992) (9 males and 6 females, mean age = 56.67 ± 12.48), were recruited for the study from a local community. PD patients were in the moderated stage (Hoehn and Yahr 1.5–2). Inclusion criteria for participants was diagnosis of idiopathic PD, the ability to walk for 10 min without stopping or walking assistance, absence of neurologic disorders other than PD, not being treated with deep brain stimulation, and absence of orthopaedic, cardiovascular or visual disturbances that could affect gait. The participants did not use a treadmill for at least 12 months before the experiment. No participant showed dementia as assessed by the mini-mental state examination (MMSE ≤ 24). The level of severity of the motor signs associated with PD was measured using

the Unified Parkinson's Disease Rating Scale Part-III (Fahn S, Elton R; 1987) (UPDRS-III) and Hoehn and Yahr modified scale (Hoehn MM, 1967) (H&Y). Tests were conducted with the patients in the "ON" state (45 min.–1.5 h after medication intake) when they were moving freely and easily without dystonia, excessive rigidity, or tremor. All participants gave their informed consent according to the declaration of Helsinki (1964), before entering the study. The experimental procedures were approved by the local ethics committee. Details of participants are shown in Table 1.

2.3. Procedures

All participants performed three sessions, one familiarization session with the treadmill and two experimental sessions corresponding to the two walking conditions: overground walking and treadmill walking. The two experimental sessions were arranged in random order and separated by a period of 1 week. A summary of the experimental procedure is shown in Fig. 1.

Spinal measurements, gait overground test performance and corticospinal measurements were recorded, in that order, before (pre) and after (post) each walking condition. Spinal measurements were tested first, to exclude the possibility that the post-measurements of the gait overground test may mask possible spinal modulations. Corticospinal parameters were measured at the end, to ensure that the post-measurements of the gait overground test took place at least 10 minutes after each of the walking conditions (Bello, Sanchez, & Fernandez-del-Olmo,

Table 1
Details of PD participants

Patient number	Sex	Age (Yr)	Weight (Kg)	Height (cm)	Leg length (cm)	Disease Duration (yr)	H&Y	UPDRS III	MMSE	More symptomatic or onset side	Medication
1	M	45	84	170	87.5	7	2	30	30	L	Levodopa/Carbidopa 750/187,5, Entacapone 1000, Pramipexole 2.1, Rasagiline 1
2	M	85	69	180	90.1	16	3	58	27	R	Levodopa/Carbidopa 600/150, Entacapone 800
3	M	42	87	175	92	2	1.5	18	28	L	Levodopa/Carbidopa 200/50, Entacapone 200
4	F	67	51	151	80.5	4	1.5	21	29	L	Levodopa/Benserazide 250/50, Rasagiline 1
5	F	51	62	160	88	10	2	21	29	I	Levodopa/Carbidopa 800/400, Pramipexole 3.15, Amantadine 300
6	M	67	81	174	91	8	1.5	9	30	L	Levodopa/Carbidopa 450/112.5, Entacapone 600, Pramipexole 3.6
7	F	45	64	171	93	7	1.5	21	30	L	Levodopa/Carbidopa 150/25, Trihexyphenidyl 2.
8	M	60	85	165	82	5	1.5	23	30	R	Levodopa/Benserazide 175/43.75, Pramipexole 2.1
9	M	36	86	168	90	4	1	9	29	R	Levodopa/Carbidopa 150/37.5 Entacapone 600, Rotigotine 4, Rasagiline 1
10	M	59	75	170	83.5	2	1.5	32	30	R	Rasagiline 1, Pramipexole 1
11	M	56	75	173	90	3	2.5	26	30	L	Levodopa/Carbidopa 350/75 Rasagiline 1, Rotigotine 8
12	F	67	67	147	74	3	1.5	18	29	R	Rasagiline 1
13	F	49	73	150	77.5	8	1.5	12	26	R	Levodopa/Carbidopa 500/125 Pramipexole 1
14	F	62	76	160	85	10	1.5	12	30	L	Levodopa/Benserazide 900/225, Ropinirole 16, Rasigiline 1,
15	M	59	75	165	91.1	9	2	16	27	R	Levodopa/Carbidopa 300/75, Rasagiline 1, Ropinirole 6,
Mean		56.67	74.00	154.18	86.35	6.53	1.68	21.23	28.93		
DS		12.48	10.13	43.32	5.73	3.86	0.46	12.20	1.33		

Yr, years; M, male; F, female; R, right; L, left.

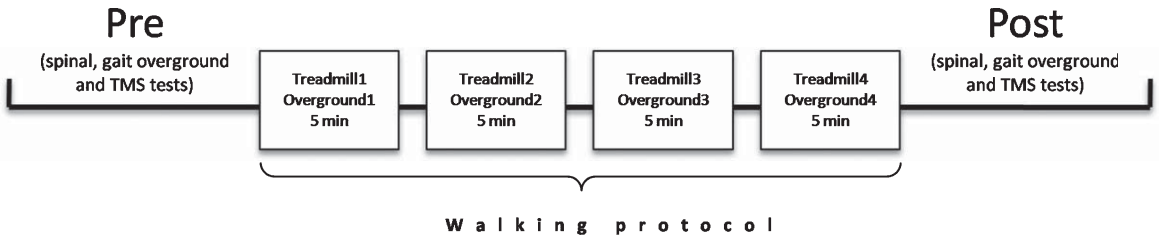

Fig. 1. Scheme of the experimental procedure. The two experimental sessions (treadmill and overground) were arranged in random order and separated by a period of 1 week. The walking conditions consisted of four 5-min blocks (Bock 1-4) of treadmill or overground walking with a 3-minute rest (R) period between blocks.

2008). The self-selected gait speed obtained during the first gait overground test, was used for the subsequent walking conditions.

The treadmill walking condition consisted of four 5-min blocks of treadmill walking with a 3 minutes rest period between blocks. During the first minute of each block, the belt speed was increased to the overground self-selected, preferred speed. All the participants walked on the treadmill holding the handrails since some participants did not feel safe to walk without the handrail support. The subjects walked on a motorized treadmill (SporsArt 6300, Sports Arts Fitness) under the close supervision of a physical therapist.

The overground condition consisted of four 5-min blocks of overground walking with a 3 minutes rest period between blocks. The overground walking session was conducted in an indoor facility. PD participants had to walk forming a square marked with cones (20×20 m). The walking direction was alternated in each block, either clockwise or counterclockwise. The walking speed was monitored during the session, in order to confirm that each patient maintained the overground walking speed obtained at the beginning of the experimental session.

2.4. Outcome measures

2.4.1. The gait overground test

Gait performance was recorded overground using an optical detection system (Optogait, Microgait, USA), after a familiarization trial. Participants were recorded walking up and down an 8-meter walkway at their self-selected comfortable speed, for a total time of 2 minutes. The gait parameters were recorded during the straight walking portion, but not during the turns.

The following gait variables were evaluated: speed (m/s), stride length (m), stride frequency (Hz), coefficient of variation (CV) of the stride length (%) and of the stride frequency (%). CV is an indicator of variability, where CV = (standard deviation/ mean) $\times$ 100.

2.4.2. Neurophysiologic measurements

Spinal and corticospinal recordings were performed at rest before and after each walking condition. Subjects were seated comfortably in a reclining armchair; with the feet resting on a foot support so that the hips were flexed at a 120 degrees, the knees semi-flexed at 20 degrees, and the ankles were positioned at 20 degrees of a plantar flexion.

Electromyographic (EMG) was recorded by a pair of adhesive surface electrodes 2-cm apart (bipolar), placed over the Soleus and Tibial Anterior muscle bellies, according to SENIAM (surface EMG for non-invasive assessment of muscles) recommendations (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). Muscles from the more symptomatic side of the PD patients were recorded. The reference electrode was placed over the medial malleolus bone surface. The recording sites were shaved, abraded and cleaned with isopropyl alcohol to obtain low impedance (Z, 5kΩ). The EMG signals were filtered (10 Hz to 1 kHz) with a sampling rate of 5 kHz and amplified with a Digitimer D360 amplifier (Digitimer Ltd., Welwyn Garden City, Hertfordshire, UK), and then recorded using SIGNAL software (Cambridge Electronic Devices, Cambridge, UK).

2.4.3. Hmax/Mmax ratio

The electrical stimulation of Ia fibres in peripheral nerves elicits the monosynaptic component of the stretch reflex, which can be recorded from the muscles as an action potential (H-reflex). Understanding the reflex control of the ankle extensors, and particularly the stretch reflex, is of relevance in human walking (Capaday, 2002). To compare H reflexes between subjects and conditions, reflex amplitude is often normalized to the maximum evoked motor

response (Mmax) (Zehr, 2002). In the present study, transcutaneous electrical stimulation of the posterior tibial nerve was used to elicit the H-reflex in the Soleus muscle using a Digitimer stimulatior (model DS7, Welwyn Garden City, UK). The optimum site of nerve stimulation was first located using a hand-held electrode. The cathode (2 cm diameter brass hemisphere) was placed on the popliteal fossa and the anode (5 cm2) above the patella. The adhesive electrodes were fixed with an elastic strap and remained in place during walking. The stimulus that was used was a rectangular pulse with a duration of 1 ms. The maximum H-reflex response (Hmax) and the maximum M amplitude (Mmax) were recorded.

2.4.4. Reciprocal Ia-inhibition

The amount of reciprocal inhibition between ankle flexors and extensors is modulated during gait cycle, to ensures that antagonistic motoneurons are not activated inappropriately (Petersen, Morita, & Nielsen, 1999). To evaluate the reciprocal Ia-inhibition from the Tibialis anterior to the Soleus muscles, the size of the Soleus control H-reflex was adjusted to Hmax/2 (Crone, 1990) and to 20–25% of the Mmax, and kept constant throughout the experiment. The conditioning stimulus was applied to the common peroneal nerve through bipolar electrodes placed at the neck of the fibula. Rectangular pulses of 1 ms duration were used. The conditioning stimulus was adjusted to the Tibialis anterior motor threshold intensity. Special care was taken to ensure a pure Tibialis anterior contraction (Meunier, Pol, Houeto, & Vidailhet, 2000). The conditioning–test interstimulus interval was determined using 0.5 ms steps until the maximum reciprocal Ia-inhibition of SOL H-reflex response was reached, and this value was then kept constant throughout the experiment. Ten unconditioned and ten conditioned reflexes were recorded. Mean as well as standard error of the mean (SEM) values are reported. The amount of inhibition was defined as: [(mean control H value – mean conditioned H value)/mean control Hvalue)] × 100.

2.4.5. Corticospinal measurements

It is often suggested that the corticospinal tract has a relevant role in the control of gait. Paired-pulse paradigms elicited with transcranial magnetic stimulation (TMS) is an easy and painless method of obtaining information about the functional intracortical network processes. In line with the literature, this methodology appeared to be the most sensitive tool to highlight intracortical abnormalities in PD (Bareš & Kaňovský, 2003; Valls-Solé et al., 1994).

The following measures, elicited by transcranial magnetic stimulation (TMS), were recorded: the motor evoked potential (MEP), short intracortical inhibition (SICI) and intracortical facilitation (ICF) of the Tibialis anterior muscle. TMS was delivered using a double cone coil connected to a Magstim 200 magnetic stimulator (Magstim, Dyfed, United Kingdom). The optimal scalp location was determined by placing the coil over the interhemispheric scissura and by moving it around until the hotspot that was contralateral to the most affected side, was located. We determined the resting motor threshold (RMT) in accordance with the International Guidelines(Rossini et al., 1994): the nearest 1% of the maximum stimulator output was defined as the minimum stimulus intensity required to produce MEPs of $> 50\ \mu V$ in at least 5 of 10 consecutive trials. In the paired-pulse TMS recordings, a subthreshold conditioning stimulus was delivered at 80% of the RMT, following a suprathreshold test stimulus intensity set at 130% of the RMT. Based on results observed by Vacherot et al. (2010), SICI was elicited at an interstimulus interval of 3 ms, whereas ICF was elicited at an interstimulus interval of 15 ms (Vacherot, Attarian, Vaugoyeau, et al., 2010). A total of 10 tests, 10 SICIs and 10 ICFs stimuli were randomly delivered and recorded in a single block (Kujirai et al., 1993). SICI and ICF amplitudes were expressed as the percentage of the mean amplitude of the unconditioned MEP.

2.5. Statistical analysis

The following variables violated the assumption of normality: CV of stride length, CV of stride frequency, Hmax/Mmax ratio, SICI and ICF variables. Those variables were analysed with non-parametric tests (Wilcoxon rank test) with the exception of SICI and ICF variables that were transform to logarithmic values.

To explore the changes in walking performance and of the neurophysiological parameters before and after each walking condition, a two-way ANOVA, with "condition" (treadmill and overground) and "time" (pre and post) as the main factors, was performed for each of the following variables: gait speed, stride length, stride frequency, MEP, Reciprocal Ia-inhibition, ICF and SICI. *Post Hoc t*-tests were computed using the Bonferroni correction.

All statistical analyses were performed using PASW Statistics 18. A P value ≤ 0.05 was considered statistically significant.

3. Results

The results of the gait parameters and the neurophysiological measurements are shown in Table 2.

3.1. The gait overground test

The analysis of the overground gait speed showed a significant condition × time interaction ($p = 0.019$) without significant main effects for condition and time. *Post hoc* analysis showed that gait speed was faster for post-treadmill compared with pre-treadmill ($p = 0.001$). No significant gait speed changes were found for the pre vs. post-overground condition (Fig. 2).

The analysis of the stride length also showed a significant condition × time interaction ($p = 0.043$) without significant main effects for condition and time. *Post hoc* analysis showed that the stride length was longer post-treadmill compared with pre-treadmill ($p = 0.007$). No significant changes were found for the overground condition (Fig. 2). The analysis for the remaining gait parameters did not show significant main effects or interactions (Fig. 2).

3.2. Neurophysiological measurements

The Wilcoxon rank test revealed a significant difference before and after treadmill ($Z = 3{,}237$; $p = 0.001$) and overground ($Z = 2{,}385$; $p = 0.017$) walking conditions. The Hmax/Mmax ratio was lower after than before the two walking conditions (Fig. 3). No significant main effects or interactions were found for the reciprocal Ia-inhibition.

The analysis of the absolute MEP amplitudes for single TMS pulses did not show significant main effects nor a significant interaction. The analysis of ICF values showed a significant main effect for time ($p = 0.019$), without a significant effect of condition or a condition × time interaction. ICF values decreased after, compared with before, the two walking conditions (Fig. 3). No significant main effects or interactions were found for measurements of SICI (Fig. 3).

4. Discussion

The current study demonstrated that a single session of treadmill walking, but not of overground walking, lead to immediate short-term gait improvements in PD patients. However, the spinal and corticospinal modulations that were observed in our study were not specific to the therapeutic effect of treadmill walking.

Our study showed that PD participants increased their overground gait speed and stride length after, compared to before, a 20 minutes session of treadmill walking. Previous findings have reported similar improvements in PD gait after a single session of treadmill walking(Bello et al., 2008; Kurtais, Kutlay, Tur, Gok, & Akbostanci, 2008; Miyai et al., 2000). For instance, overground gait speed, stride length and double stance duration have been shown to improve after a single session of treadmill walking with weight support. However, none of these studies have compared a single session of treadmill walking with a single session of overground walking. To our knowledge the current study is the first to show that 20 minutes of overground walking does not

Table 2
Mean and standard deviations of gait variables before, and after a single session intervention

	Treadmill		Overground	
	Pre	Post	Pre	Post
Gait speed (m/s)	1.17 (0.26)*	1.25 (0.24)*	1.21 (0.19)	1.20 (0.22)
Stride length (m)	1.23 (0.19)*	1.29 (0.18)*	1.26 (0.17)	1.23 (0.16)
Stride frequency (Hz)	0.94 (0.09)	0.95 (0.09)	0.95 (0.07)	0.97 (0.09)
CV of stride length (%)	4.52 (2.01)	3.94 (1.78)	4.30 (1.78)	4.22 (2.29)
CV of stride frequency (%)	3.08 (1.41)	2.84 (1.06)	2.90 (1.32)	2.85 (1.47)
Hmax/Mmax ratio (%)	49.29 (0.28)*	35.32 (0.27)*	47.10 (0.24)*	37.72 (0.22)*
Reciprocal Ia-Inhibition	8.00 (6.75)	5.34 (8.04)	4.35 (8.70)	2.49 (7.10)
ICF(%MEP)	5.02 ± 0.31*	4.82 ± 0.34*	4.88 ± 0.32*	4.79 ± 0.35*
SICI(%MEP)	3.80 ± 0.56	3.80 ± 0.61	4.04 ± 0.49	3.87 ± 0.58

Pre, pretest; Post, postest; CV, coefficient of variation, * ($p < 0.005$).

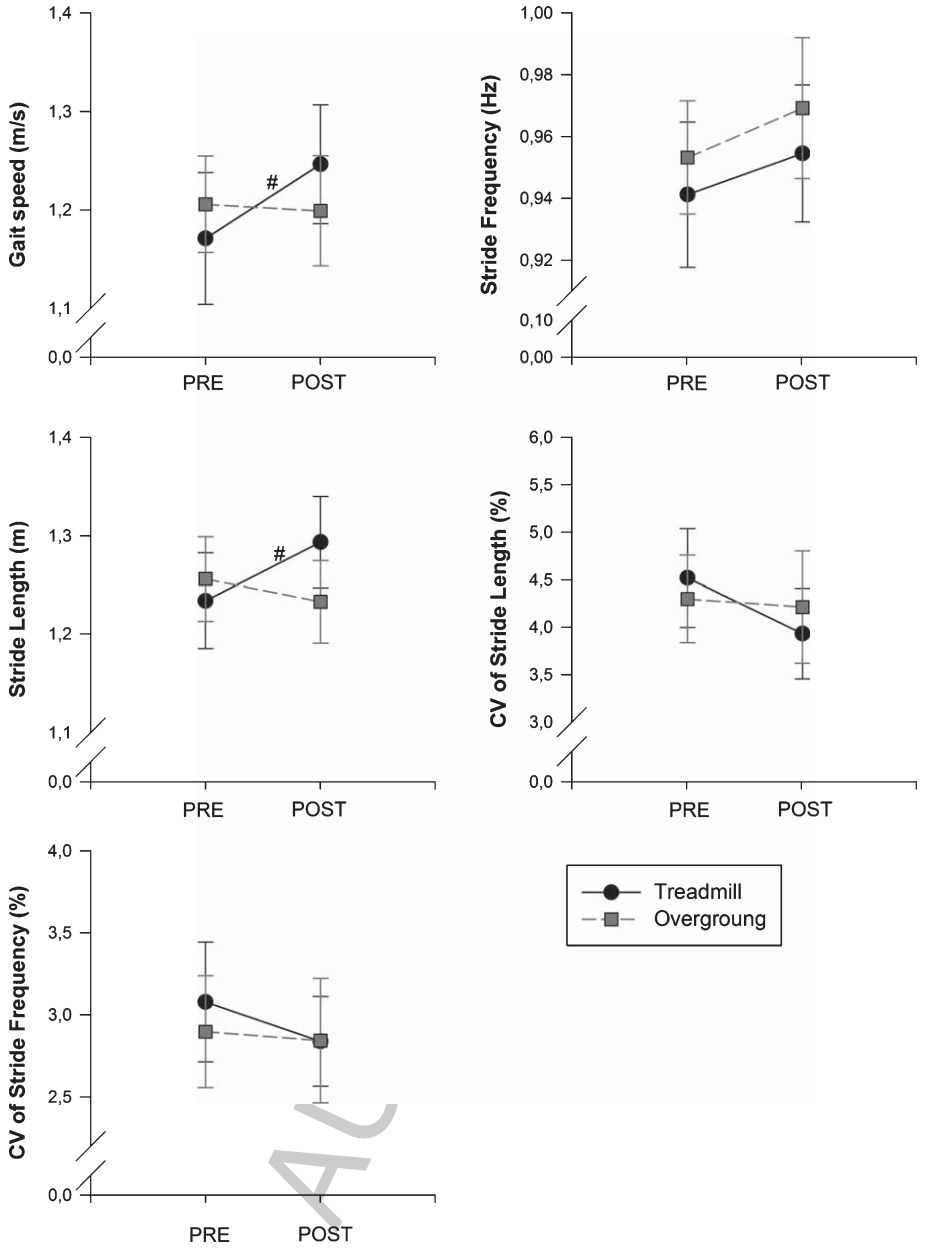

Fig. 2. Results of walking performance. PRE, pretest; POST, postest; #, ($p < 0.005$).

improve gait in PD. Therefore, our results suggest a specific therapeutic effect of treadmill walking in PD subjects.

The current investigation did not demonstrate any significant difference between neurophysiological measures across the two walking condition, i.e. treadmill and overground walking.

The current study showed that the SICI values did not change after a single session of treadmill and overground walking. A previous study on upper limb showed that dopaminergic substitution therapy mainly acted on inhibitory processes, restoring the intracortical abnormalities, increasing the SICI(M. Pierantozzi et al., 2001). However, later studies suggested that intracortical abnormalities in PD seem to differ between the upper and lower limbs cortical areas (Tremblay, 2012; Vacherot, Attarian, Eusebio, & Azulay, 2010; Vacherot, Attarian, Vaugoyeau, et al., 2010). Those studies indicated that the cortical areas responsible for the lower limb movements

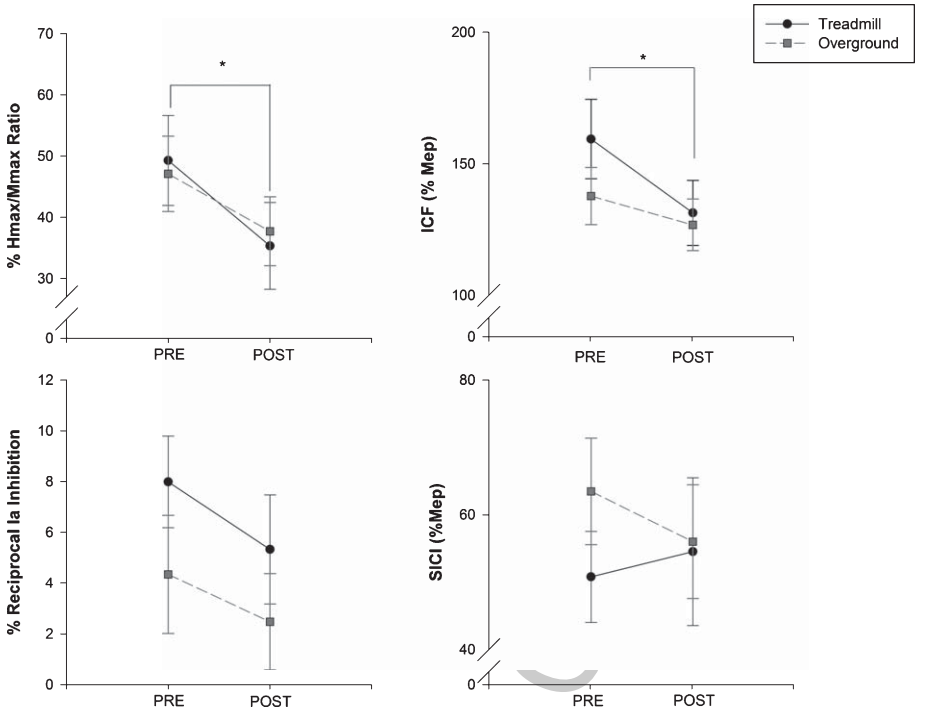

Fig. 3. Results of spinal and cortical excitability. PRE, pretest; POST, postest; ICF, intracortical facilitation; SICI, short intracotical inhibition*, significant main effect ($p < 0.005$).

showed ICF impairments, whereas the SICI remained unaffected, which is in agreement with our results. In addition, SICI has been shown to be mediated by cortical $GABA_a$ activity (Werhahn, Kunesch, Noachtar, Benecke, & Classen, 1999; Ziemann, Lönnecker, Steinhoff, & Paulus, 1996) and can be modulated by a short period of motor skill training involving ankle muscles (Monica a Perez, Lungholt, Nyborg, & Nielsen, 2004). Several studies have suggested that gait improvements associated with treadmill walking may be related to motor learning mechanisms, since the improvements are sustained for several months after the treadmill training has been completed (Fisher et al., 2008; Herman, Giladi, Gruendlinger, & Hausdorff, 2007; Protas et al., 2005). However, our SICI findings suggest that it is unlikely that the gait improvements, observed after a single session of treadmill walking, are related to the acquisition of a motor skill.

We found that ICF values decreased after both walking interventions in PD patients. Thus, the observed ICF reduction was not specific to the treadmill, but instead as a result of the walking movement itself. A previous study found an abnormal reduction in ICF in PD patients that correlated with a shortened stride length and reduced gait velocity in those patients (Vacherot, Attarian, Vaugoyeau, et al., 2010). Therefore, we would expect to find that the treadmill walking session would lead to an improvement in the gait kinematics in PD subjects and a specific modulation on ICF. However, our findings suggest that ICF is not a mechanism underlying the gait improvement associated with treadmill walking in PD. It must be taken into account that it is difficult to compare the results of the study of Vacherot et a. (2010) with our current findings since, unlike our study, ICF values were measured before any walking activity was performed and half of the patients manifested freezing of gait (Vacherot, Attarian, Vaugoyeau, et al., 2010), which reflect a more severe gait impairment. It is possible that the severity of the disease may affect intracortical facilitation mechanisms and could thus account for the contrasting findings (Wu, Fregni, Simon, & Deblieck, 2008). Further studies are needed to explore the relationship between ICF and gait parameters in PD.

In addition, we observed spinal modulations after both the treadmill and walking sessions as indicated by a reduction of the Hmax/Mmax ratio values. However, we did not observe any significant changes in the reciprocal Ia-inhibition. A previous study showed that the Soleus Hmax/Mmax ratio and the recruitment

curve of H-reflex at rest are similar in PD and control subjects (Dietrichson, 1971). However, several other studies have suggested that this reflex has a role in the gait impairments that are observed in PD (Hiraoka et al., 2005; Hiraoka, Matuo, Iwata, Onishi, & Abe, 2006; M Pierantozzi et al., 2008). There is some evidence to suggest that the depression of the SOL H-reflexes can occur after different training tasks such as a single training session of cycling (Sabine Meunier et al., 2007), balance (Freyler, Weltin, Gollhofer, & Ritzmann, 2014), and co-contraction (Perez et al., 2007) in healthy adults. Thus, it is likely that the depression of the Hmax/Mmax ratio observed in the present study may be due to the actual walking activity. In addition, it has been reported that reciprocal inhibition increases during human walking to ensure that antagonist muscles do not become too active. However, there were no changes in this parameter in the present study (Petersen et al., 1999). Thus, our findings suggest that both the H-reflex and the reciprocal Ia-inhibition are not involved in the gait improvements associated with a single session of treadmill walking in PD.

Further studies are needed to elucidate the neural mechanisms involved in treadmill walking improvements in PD, perhaps using other neurophysiologic parameters and techniques. For instance, presynaptic inhibition of Ia afferents and Renshaw cell inhibition are others of spinal mechanisms that contribute to phase-dependent soleus H-reflex modulation during human walking (Knikou, 2010). In addition to the TMS paired-pulse paradigm, the use of motor subthreshold TMS pulses during walking (Christensen, Petersen, Morita, & Nielsen, 1998) could provide more information about the corticospinal contribution to gait control in PD. We should stress that the aim of the current pilot study was to explore the short-term effects of a single treadmill session and thus, the possible neurophysiological long-term effects as a result of several sessions remain to be studied.

4.1. Clinical implications

Our results clearly indicate that a single session of treadmill walking provides a benefit in the gait of PD patients in comparison with the lack of gait improvements after a session of overground walking. This finding supports the therapeutic use of treadmill walking to improve the gait in PD subjects. Although, we did not find modulation of several neurophysiological parameters that could account for the therapeutic effect of treadmill walking in PD, it is of relevance to expand this line of research to improve the effectiveness of the rehabilitation treatments.

4.2. Study limitations

There are several limitations in this study that must be addressed. First, the severity of the disease of the PD participants in our study was moderate. It would be of relevance to replicate the study in more advanced PD patients, since gait improvements as a result of treadmill training have been shown to be more marked in advanced compared with moderate PD subjects (Bello et al., 2008). Second, this is a pilot study that explores for first time the short-term neurophysiologic effects of a single session of treadmill in comparison with overground walking. Due to the small sample size of this study, our findings must be interpreted with caution. Further studies with larger sample sizes are needed. Third, several neurophysiological parameters (i.e. SICI and ICF) were obtained at rest rather than during walking. Although, we were aware that these parameters would be functionally more informative if they were recorded during movement, it would have been a methodological challenge. Fourth, it could be possible that stride-to-stride variation of PD participants during the overground walking has been exacerbated by the requiring turns, which could have an impact on the measured gait parameters. However, it should be noted that our results did no show differences in gait variability between both walking experimental conditions. Finally, we did not include control subjects since one of the main goals of this study was to compare neurophysiological parameters in PD patients across different walking conditions rather than with healthy subjects. However, future studies including control subjects are warranted in order to determine whether the spinal and cortical modulations that are associated with treadmill and overground walking are specific to PD.

5. Conclusion

The current study demonstrated that a single session of treadmill walking, but not of overground walking, could lead to gait improvements in PD patients. However, our findings suggest that measures of spinal and cortical modulations such as monosynaptic and reciprocal inhibition, as well as SICI and ICF, could be not associated with the specific therapeutic effect of treadmill walking in PD.

Acknowledgments

This work has been supported by Ministerio de Economía y Competitividad, Spain [ref. DEP-2014-53896_R].

Conflict of interest

The authors declare that they have no conflict of interest.

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