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Walking on a treadmill improves the stride length-cadence relationship in individuals with Parkinson's disease

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A R T I C L E I N F O

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A B S T R A C T

Background: The gait pattern in Parkinson´s disease (PD) is characterized by a deficit in the internal regulation of stride length (SL), while the control of cadence (Cad) remains intact. The use of the treadmill as a gait rehabilitation tool has provided novel options for treatment of gait impairments in PD. However, it remains unclear whether walking on the treadmill changes the stride length–cadence relationship (SLCrel) in PD. The purpose of the present study was to analyze the SLCrel in PD subjects walking on a treadmill vs. overground, and to further compare the SLCrel to that of age-matched healthy subjects.

Methods: Fifteen PD subjects and fifteen age-matched controls walked overground and on a treadmill at five different self-selected speeds. Gait speed, SL and Cad were recorded at each self-selected speed. A linear regression analysis was conducted to explore the SLCrel and to determine the slope and intercept for each participant.

Results: PD subjects showed a lower intercept than control subjects when walking both overground and on a treadmill ($F = 8.51$, $p = 0.007$). In comparison with walking overground, walking on a treadmill resulted in a significant increase in the intercept in both PD and control groups ($F = 12.17$, $p = 0.002$). There were no significant differences in the slope of the SLCrel.

Conclusion: PD subjects are able to improve the internal regulation of SL when walking on a treadmill. Our results confirm the potential therapeutic effects of treadmill training for gait rehabilitation in PD and suggest that the mechanisms underlying the positive effects of treadmill training on PD subjects are sustained.

1. Introduction

Parkinson's disease (PD) is a progressive neurodegenerative disease that affects motor functions [1]. PD is clinically characterized by symptoms of akinesia, rigidity, tremor and postural instability [1]. However, gait disturbances are one of the most disabling symptoms of PD, potentially leading to loss of mobility, increasing numbers of falls [2] and negative affects on the independence and quality of life of PD patients [3].

Gait in PD is associated with shorter stride lengths (SL), while the cadence (Cad) remains intact [2,4]. When PD patients and healthy adults increase or decrease their self-selected walking speed, they respectively increase or decrease their SL and Cad in a relatively constant linear relationship [5,6]. In PD subjects, the slope of this relationship remains unaffected, but the intercept is lower than that of healthy subjects, that is, a smaller SL is associated with a higher Cad. This difficulty in the regulation of SL can be normalized by using attentional strategies [7] or Levodopa medication [8], suggesting that the ability for PD patients to generate a normal stride length-cadence relationship (SLCrel) is not lost [7].

For this reason, the regulation of SL must be prioritized as one of the main goals in rehabilitation interventions in PD patients. The use of treadmills in gait rehabilitation in PD patients has been proven to improve gait performance [9–13]. While treadmill walking training has been found to increase the SL in PD subjects, walking training overground lacked such an improvement [14]. Additionally, advanced PD subjects walking on a treadmill increased their SL whereas walking at the same speed overground had no effects [10]. Taking these results together, it could be suggested that the treadmill could help to normalize the SLCrel in PD subjects [15]. However, no study to date has explored the SLCrel in neither PD nor healthy subjects walking on a treadmill. Therefore, the goal of the current study is to compare the SLCrel in PD subjects walking on a treadmill vs. overground. In addition, the SLCrel in age-matched healthy subjects was evaluated in order

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to explore whether the treadmill had similar effects in both groups. The results could extend previous findings and confirm the potential therapeutic effects of treadmill walking for gait rehabilitation in PD.

2. Methods

2.1. Participants

Fifteen subjects with PD (11 males and 4 females, mean age 65.4 ± 9.23) and fifteen age matched controls (10 males and 5 females, mean age 64.07 ± 8.01) with no history of neurological disorders participated in the study. Subjects were required to be able to walk without assistance. All subjects were familiar with the treadmill. Participants with any medication that could influence their ability to walk were excluded from the experiment. Data collection was carried out with subjects in an "ON" medication state (45–90 min after medication intake), which was confirmed by a neurologist. No participant showed signs of dementia, as assessed by a mini-mental state examination (MMSE). The level of severity of motor signs associated with PD was measured using the Unified Parkinson's Disease Rating Scale Part-III (UPDRS-III) [16] and Hoehn and Yahr scale (H&Y) [1]. Height, weight and leg length were collected from all participants. Details of the subjects are shown in Table1. All participants gave their written informed consent according to the declaration of Helsinki (1964) before partaking in the study. The experimental procedures were approved by the ethics committee of University of A Coruña.

2.2. Procedure

In order to avoid any carry-on effect from treadmill walking, all participants first performed the overground walking test followed by the treadmill walking test [10].

2.3. Overground walking test

Kinematic gait parameters were recorder using an optical detection system and specialized software v.1.11 (OptoGait; Microgait, Italy). This optical and modular system includes transmitting and receiving bars of infrared LEDs displayed in parallel along 5 m of walkway. Each bar contains 96 light diodes at 1.04 cm of horizontal distant between each diode. When subjects enter the area limited by the bars, their feet block the transmission and reception and spatial (foot placement) and temporal (time of the foot placement) data are transfer to a personal computer. Therefore, stride length and cadence are directly obtained by the OptoGait software (OPTOGait Version 1.11 software) while speed is estimated from both parameters. The walkway was 9 m long with 5 m of electronic walkway in the middle zone. The protocol followed was that used by several previous studies [17,18]. Gait speed, SL and Cad were collected at five different self-selected speeds: preferred, slow, very slow, fast and very fast. All subjects performed three consecutive trials for each speed condition, with each trial consisting of walking straight down and back the walkway. Trials at the subject's preferred speed were always recorded first to avoid any influence from the other speed conditions. The remaining four gait paces were performed in the order of either slow, very slow, fast and very fast, or fast, very fast, slow and very slow. Participants were randomly assigned to one of these two orders. For each trial, participants started walking two meters before the electronic walkway and finished two meters after the end of the walkway in order to avoid recording the acceleration and deceleration of the participants. The second and third walks of each self-selected speed were averaged to obtain one value per participant. PD participant's rested between self-selected speeds as necessary.

Table 1
Group characteristic.

	PD	CONTROL
Age, yrs	65.40 ± 9.23	64.07 ± 8.01
Male, n	11	10
Female, n	4	5
Weight, kg	73.30 ± 14.65	73.77 ± 14.88
Height, cm	166.27 ± 10.71	164.33 ± 10.70
Leg length, cm	86.20 ± 5.71	83.77 ± 6.38
UPDRS-III	16.4 ± 5.89	–
H&Y stage (subject in each stage)	1 (n = 1); 1.5 (n = 1); 2 (n = 12); 2.5 (n = 1)	–

Note: PD, Parkinson's disease subjects; Means ± SD; UPDRS-III Unified Parkinson's Disease Rating Scale motor section, H&Y Hoen and Yahr.

2.4. Treadmill walking test

The overground speeds were used to set the treadmill speeds for each participant. As a warm up prior to testing, each participant performed two minutes of walking at approximately their lowest speed. The treadmill session consisted of five 1-min blocks (T1–T5) of treadmill walking, with one minute at each of the five speeds ranging from very slow to very fast. Speed of the treadmill was always checked by a digital tachometer (Hibok-24) with a special built-in sensor to measure surface velocity. Measurements on the treadmill were taken from the last 30 s of each block by the Optogait system (two parallel bars installed in the laterals of the belt). All participants walked on the treadmill holding the handrails under supervision and with a safety harness to prevent falls. All subjects were able to walk on the treadmill at their five self-selected overground speeds.

2.5. Complementary experiment

In order to control for the effect of using the handrails during treadmill walking in the main experiment, we asked the participants to partake in a second experimental session. The procedure was identical to the main experiment, however the participants were to walk without holding the handrails during the treadmill walking. Six PD participants who felt confident enough to walk on the treadmill under these conditions and six control participants took part in this complementary experiment.

2.6. Data analysis

We analyzed the following gait variables: speed, SL and Cad. SL was normalized by dividing the mean SL for each self-selected speed by the leg length [19]. Linear regression analysis was used to evaluate the SLCrel and to determine the slope, intercept and R^2 for each participant. A linear relationship between SL and Cad was defined as that having R^2 values greater or equal to 0.80 [18]. We calculated the intercept for Cad of 100 steps/min to ensure that the intercept values were within the data range for all the participants [17,18,20]. In addition, walks with very high Cad (greater or equal to 150 steps/min) were removed from the analysis [17,18,20].

2.7. Statistical analysis

ANOVA with repeated measurements in CONDITION (overground, treadmill), SPEED (very slow, slow, preferred, fast and very fast), and GROUP (PD, control) as factors were conducted in order to explore changes in SL, Cad, and speed between conditions and groups. Post-hoc analysis was conducted using a Bonferroni adjustment.

Similarly, ANOVA with repeated measurements in CONDITION (overground, treadmill) and GROUP (PD, control) were used to compare the intercept, slope and R^2 between conditions and groups.

For the complementary experiment, ANOVA with repeated measurements in CONDITION (overground, treadmill without handrails) and GROUP (PD, control) were conducted over the intercept and slope.

Table 2
Gait parameters in PD and control subjects during overground and treadmill conditions.

	PD (n = 15) Overground Treadmill Mean (SD) Mean (SD)	CONTROL (n = 15) Overground Treadmill Mean (SD) Mean (SD)
Speed VS (m/sec)	0.85 (0.13) 0.84 (0.13)	0.89 (0.18) 0.89 (0.18)
Speed S (m/sec)	1.04 (0.16) 1.04 (0.15)	1.08 (0.18) 1.08 (0.18)
Speed Pref (m/sec)	1.24 (0.19) 1.24 (0.20)	1.28 (0.20) 1.28 (0.20)
Speed F (m/sec)	1.38 (0.22) 1.38 (0.23)	1.46 (0.22) 1.45 (0.22)
Speed VF(m/sec)	1.54 (0.23) 1.54 (0.23)	1.68 (0.24) 1.69 (0.25)
SL VS (m)	1.04 (0.14) 1.10 (0.15)	1.13 (0.12) 1.18 (0.17)
SL S (m)	1.17 (0.16) 1.22 (0.17)	1.25 (0.13) 1.29 (0.13)
SL Pref (m)	1.28 (0.19) 1.32 (0.17)	1.34 (0.14) 1.39 (0.13)
SL F (m)	1.35 (0.20) 1.38 (0.18)	1.44 (0.15) 1.47 (0.13)
SL VF(m)	1.43 (0.21) 1.46 (0.19)	1.53 (0.17) 1.53 (0.18)
Cad VS (step/min)	97.83 (7.41) 92.17 (8.36)	93.91 (10.58) 90.43 (12.73)
Cad S (step/min)	107.25 (7.48) 102.27 (6.77)	104.91 (10.27) 100.92 (11.51)
Cad Pref (step/min)	116.86 (7.22) 111.75 (5.27)	116.41 (10.71) 109.71 (12.27)
Cad F (step/min)	123.21 (8.01) 116.58 (7.17)	123.02 (10.50) 112.95 (9.24)
Cad VF (step/min)	129.51 (8.98) 124.51 (6.94)	132.45 (11.30) 125.48 (13.44)

Note: PD, Parkinson's disease subjects; SD; standard deviation, VS; very slow, S; slow, Pref; preferred, F; fast, VF; very fast; nSL, normalized stride length; Cad, cadence.

All data were analyzed using SPSS for Windows (version 14.0; SPSS Inc, Chicago, IL). The significance level was set at $p \leq 0.05$.

3. Results

3.1. Modulation of gait speed, stride length and cadence

Descriptive statistics of the results obtained in the two conditions of assessment are presented in Table 2.

The two-way ANOVA for gait speed showed a significant main effect for SPEED ($F = 100.66$, $p < 0.001$). There were no significant effects for CONDITION or GROUP. No significant interactions were found. Post-hoc analysis revealed significant differences in speed across all the speed values ($p < 0.001$ for all comparisons).

The two-way ANOVA for SL showed a significant main effect for SPEED ($F = 45.76$, $p < 0.001$). There were no significant effects for CONDITION or GROUP. No significant interactions were found. Post-hoc analysis revealed significant differences in SL across all speed values ($p < 0.001$ for all comparisons).

The two-way ANOVA for Cad revealed a significant main effect for CONDITION ($F = 8.79$, $p = 0.006$) and SPEED ($F = 43.93$, $p < 0.001$). There was no significant difference between groups. No significant interactions were found. The Cad was lower during treadmill walking in comparison with overground walking. Post-hoc analysis revealed significant differences in Cad across all speeds ($p < 0.05$ for all comparisons).

3.2. SLCrel analysis

One PD participant and two control participants had Cad values higher than 150 steps/min during overground walking, while high Cad values were only found in one control participant during the treadmill session; these values were not included in the SLCrel analysis.

The two-way ANOVA for intercept revealed a significant main effect for CONDITION ($F = 12.17$, $p = 0.002$) and GROUP ($F = 8.51$, $p = 0.007$) (Tables 3a, 3b). No significant interactions were found. The SLCrel intercept was lower for PD than control participants. The intercept was lower for overground walking in comparison with treadmill walking. Fig. 1 shows the intercept for PD and control participants across the two conditions.

Table 3a
SLCrel values for overground and treadmill in PD and control subjects.

	PD (n = 15) Overground	Treadmill	CONTROL (n = 15) Overground	Treadmill
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
SLCrel slope	0.015 (0.005)	0.014 (0.008)	0.014 (0.004)	0.013 (0.008)
SLCrel intercept	1.24 (0.182)	1.36 (0.150)	1.41 (0.156)	1.55 (0.284)
SLCrel R^2	0.96 (0.037)	0.89 (0.254)	0.96 (0.052)	0.87 (0.122)

The two-way ANOVA for slope did not reveal a significant main effect for CONDITION or GROUP, and no further interaction.

Examination of the SLCrel plot in the overground condition showed a positive linear relationship in each of the participants. However, in the treadmill condition, two PD participants and four control participants had less than $R^2 = 0.80$, non linear relationship. The two-way ANOVA for R^2 showed a significant main effect for CONDITION ($F = 4.52$, $p = 0.042$). There was no significant difference between groups and no interactions. In the overground condition, the average R^2 was 0.9594 ($\pm$ 0.037) in PD and $R^2 = 0.9614$ ($\pm$ 0.052) in control participants. In the treadmill condition, the average R^2 was 0.8930 ($\pm$ 0.254) in PD and $R^2 = 0.8680$ ($\pm$ 0.122) in control participants.

3.3. Complementary experiment

The ANOVA over the intercept showed a significant main effect of CONDITION ($F = 16.11$ $p = 0.002$). The intercept was lower during treadmill walking without holding the handrails in comparison with that when walking overground (Fig. 2). With the exception of one participant, all participants reduced the intercept under the treadmill condition. There was no effect of GROUP or interaction CONDITION * GROUP.

The ANOVA for slope did not reveal a significant main effect for CONDITION or GROUP, and no further interaction.

4. Discussion

The main goal of this study was to evaluate the effect of treadmill walking on the gait SLCrel in PD patients. Our results showed an increase in the intersection of the SLCrel in PD participants when walking on the treadmill in comparison with walking overground. This finding supports the use of the treadmill to normalize the SLCrel in PD patients. Interestingly, this effect was also shown in the control group, suggesting that the mechanisms underlying the modulation of the SLCrel when walking on the treadmill are preserved in the PD participants.

Our study is the first to evaluate the SLCrel when walking overground and on a treadmill in PD participants. In a previous study from our group [10], we found that advanced PD participants significantly decreased their Cad and increased their step length during the treadmill condition, while the control subjects and moderate PD patients did not significantly change their step length or Cad. However, in that study we only evaluated the self-selected preferred speed. In the current study, we used a linear regression analysis to explore the relationship between SL and Cad. Our results showed that moderate PD participants are also able to increase the SL when using the treadmill.

Several mechanisms have been proposed to explain the improvement in gait induced by treadmill training in PD [21]. For example, the treadmill may provide adequate sensory inputs, which may stimulate spinal locomotor circuitry [22,23]. Interestingly, our control group also showed a higher intersection of the SLCrel when walking on the treadmill in comparison with walking overground. Therefore, it is possible that both groups, PD and elderly healthy participants, benefit from similar mechanisms. However, PD participants could also use the sensory inputs to trigger intact circuits and by-pass the defective

Table 3b
SLCrel values for the complementary experiment.

	PD (n = 6) Overground	PD (n = 6) Treadmill	PD (n = 6) Treadmill without handrails	CONTROL (n = 6) Overground	CONTROL (n = 6) Treadmill	CONTROL (n = 6) Treadmill without handrails
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
SLCrel slope	0.012 (0.004)	0.013 (0.003)	0.016 (0.002)	0.013 (0.003)	0.015 (0.014)	0.018 (0.004)
SLCrel intercept	1.38 (0.169)	1.43 (0.122)	1.27 (0.126)	1.47 (0.079)	1.45 (0.262)	1.27 (0.128)
SLCrel R^2	0.96 (0.022)	0.96 (0.051)	0.94 (0.073)	0.97 (0.046)	0.92 (0.066)	0.95 (0.062)

Note: PD, Parkinson's disease subjects; SLCrel, stride length- cadence relationship; SD; standard deviation.

pallidocortical circuit. This extra-benefit in PD participants from the treadmill is supported by a recent study that found a more temporally organized and more regular gait pattern in the treadmill walking of PD participants compared with that of healthy participants [24]. Alternately, it is also plausible that walking on a treadmill demands more attentional resources than walking overground, allowing the patients to avoid an automatic gait control through basal ganglia - supplementary motor area in favor of an intact cerebellum - premotor area circuit.

The SL and Cad across the different self-selected speeds showed a linear relationship for each participant during overground walking. This linear relationship has been interpreted as an indicator of the integrity of high-level mechanisms by which gait control is simplified or 'automated' in steady state walking [20]. However, in the treadmill condition, two PD subjects and four control subjects had R^2 values less than $R^2 = 0.80$, displaying a non-linear relationship. In addition, R^2 values were significantly higher in the overground than in the treadmill condition for both groups. This could be interpreted as a less automated control of gait walking on the treadmill, likely due to the imposed speed of the treadmill's belt. This finding is in line with that of a previous study, where constraining SL or Cad during overground walking resulted in an inconsistent SLCrel [20].

The SLCrel modulation when walking on the treadmill could illuminate the benefits of treadmill training programs in PD patients. Improvements in balance, UPDRS scores, SL, Cad or walking speed have been reported after different treadmill training programs [9,12,13,25]. However, these improvements may have been resulted from the general benefit of exercise rather than from a specific improvement in the motor symptomology of this pathology. The analysis of the SLCrel may be useful to differentiate the specific from the general benefits of gait rehabilitation interventions. To date, the effects of treadmill training programs on the SLCrel in PD subjects have not been evaluated. Therefore, it remains unexplored/unknown whether treadmill training influences the gait pathophysiology of PD subjects.

It should be noted that there were not any differences between groups in SL and Cad at the five speeds evaluated. However, the analysis of the relationship between both parameters clearly showed a lower intercept for the PD group than for the control group, in line with the findings of previous studies [2,4,17,18]. Therefore, in order to obtain a more detailed analysis of the gait pattern, this result stresses the need to evaluate the SLCrel rather than simply evaluating both parameters separately.

We should point out that, for the main experiment, the participants walked on the treadmill holding the handrails. Since the use of handrails can improve gait stability, it may be argued that this should account for the increase in the intersection of the SLCrel when walking on the treadmill. However, this claim is unlikely since several studies have shown that PD patients actually reduce their SL when walking with a wheeled walker [26,27] and even when they use a treadmill simulator without a belt that could move on a walkway in a constant speed [11]. Moreover, our complementary experiment showed that walking on the treadmill without holding the handrails is not a suitable condition to control for the effects of the handrail in the SLCrel. Under this condition, 11 of the 12 participants had lower intersections of the SLCrel than when walking overground. Similar results have been found in our lab for young subjects (data not published).

We must point out that the participants with PD in our study demonstrated only minor hypokinesia since the SL values were similar to the control subjects. It would be of importance to explore whether the effect of treadmill walking on the SLCrel is more marked in advance compared with moderate subjects with PD

In conclusion, the current study shows that the intercept of the SLCrel increases when walking on the treadmill in comparison with walking overground in both PD and control participants. Our results confirm the potential therapeutic effects of treadmill training for the gait rehabilitation in PD and suggest that the mechanisms underlying the treadmill effects are preserved in PD subjects.

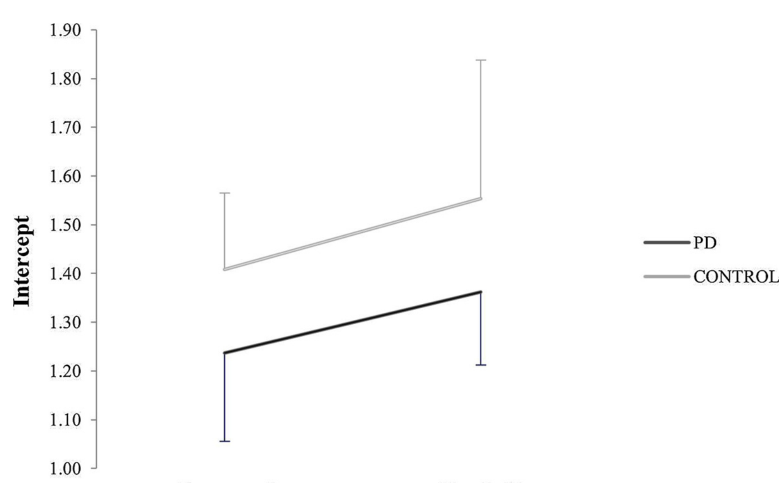

Fig. 1. Intercept for PD and control subjects across overground and treadmill conditions.

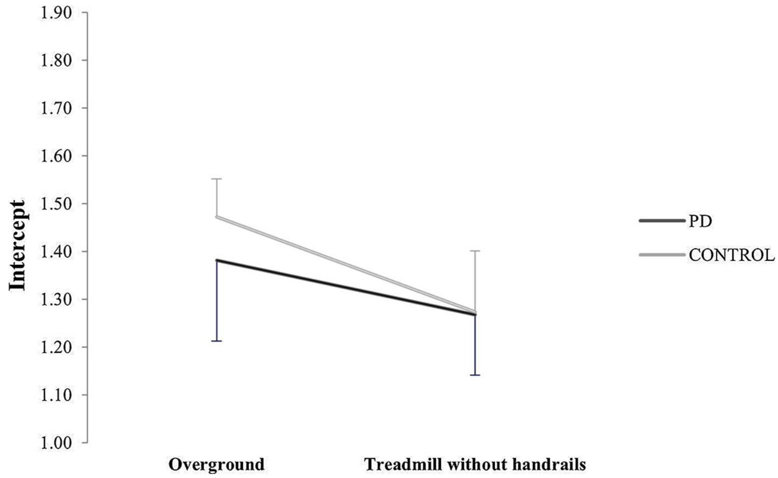

Fig. 2. Complementary experiment, intercept for PD and control subjects across overground and treadmill without handrails conditions.

Conflict of interest

All authors have no conflict of interest and no further financial disclosure to make.

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