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Sensory loss and walking speed related factors for gait alterations in patients with peripheral neuropathy

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ABSTRACT

Background: Walking instability and a higher risk of falls are common in patients with peripheral neuropathy. However, it remains uncertain as to whether alterations in neuropathic gait are directly related to deficient sensory locomotion control or due to a slowing of walking speed. By means of a multi-speed gait assessment we determined factors related to sensory loss and walking speed that cause changes in the gait pattern of neuropathic patients.

Methods: Walking patterns of 18 neuropathic patients (70.7 ± 2.4 years, 6 females) and 18 age- and gender-matched healthy subjects (70.4 ± 2.4 years, 6 females) were recorded on a pressure-sensitive gait carpet for three different locomotion speeds (i.e. slow, preferred and fast) and while walking with eyes closed. Mean temporospatial gait parameters and gait variability were analyzed. The relationship between gait alterations and the history of falls in patients was evaluated.

Results: Alterations in the mean locomotion pattern of neuropathic patients were mainly related to reduced walking speed. However, prolonged double support times ($p < 0.001$), widened base widths ($p = 0.001$) and increased gait variability ($p < 0.001$) during slow walking or with eyes closed appeared to be directly linked to peripheral sensory loss in patients. Increased gait variability was predictive for the presence of self-reported falls in the past ($p = 0.029$).

Conclusions: Sensory-loss-related prolongation of double support phases in neuropathic patients suggests a compensatory strategy to improve restabilization during locomotion. Moreover, widened base widths and increased gait variability point to an increased risk of falls. They occur primarily when patients are forced to reduce their walking speed or when visual feedback is disturbed.

1. Introduction

A stable walking pattern relies on the smooth operation of neuronal spinal and supraspinal pattern generators as well as on sensory feedback from visual, vestibular and proprioceptive systems. Peripheral neuropathy (PN) results in reduced peripheral sensibility and thereby affects proprioceptive feedback control of locomotion. Additionally, PN is linked to distal motor impairments in particular decreased ankle motor function [1,2]. Walking instability and a higher risk of falls are common in patients with PN [3,4]. Biomechanical gait analyses have shown that patients with PN walk at slower speeds, with shortened stride lengths and greater base widths, stride times and double support times than age-matched healthy controls [2,5,6]. Neuropathic gait is also characterized by increased gait variability [7], which is linked to a higher risk of falls [8]. So far however, it remains uncertain as to whether gait alterations ascribed to neuropathy are related to reduction of gait speed, distal neuropathy-associated sensorimotor impairment, or both [2,5–7,9].

Sensory feedback control is thought to play an important role in adjusting stride-to-stride limb trajectories to maintain balance and in smoothing unintended irregularities during walking [10,11]. Thus, deficient peripheral sensory feedback control should have a greater influence on the stride-to-stride variability of gait than on the mean locomotor pattern [9]. Furthermore, it has been shown that sensory feedback control of locomotion is dependent on the actual walking speed. The impact of a sensory loss or perturbation on gait decreases with increasingly faster walking speeds [12,13]

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Table 1
Characteristics and walking velocities of the study collective (mean ± SE), significant effects are marked in bold.

	HS	PN	
N	18	18	
Female/male	6/12	6/12	
Mean age (years)	70.4 ± 2.4	70.7 ± 2.4	$p = 0.938$
Mean height (cm)	174.2 ± 2.2	176.6 ± 2.1	$p = 0.444$
Mean leg length (cm)	91.2 ± 1.5	91.8 ± 1.0	$p = 0.727$
FES-I	Not rated	25.5 ± 2.3	
History of falls/no history of falls	Not rated	11/7	
Slow speed (m/s)	0.68 ± 0.04	0.42 ± 0.04	**p < 0.001**
Preferred speed (m/s)	1.08 ± 0.04	0.93 ± 0.06	**p = 0.046**
Fast speed (m/s)	1.60 ± 0.05	1.39 ± 0.08	**p = 0.030**
Speed while EC (m/s)	0.94 ± 0.05	0.69 ± 0.08	**p = 0.007**

HS – healthy subjects; PN – patients with peripheral neuropathy; FES-I – Falls Efficacy Scale-International; EC – eyes closed.

because locomotion at high speeds is thought to be more under automatic control than sensory feedback control. Functional imaging confirmed that the activity of sensory cortex areas is reduced at faster locomotion speeds [14]. Recently, a tight connection between deficient sensory feedback control of locomotion and alterations in gait variability was observed. Chronic vestibular failure and absent visual feedback control led to increased levels of gait variability during slow locomotion but normal variability during faster walking velocities [15,16].

The purpose of this study was to systematically investigate the influence of PN on the walking pattern during different locomotion speeds and during the absence of visual feedback control. Our aim was to separately identify those temporospatial gait alterations that are directly caused by deficient sensory feedback control and those that are only indirectly caused by changes in the walking speed. We hypothesized that deficient peripheral feedback control would predominantly affect the stride-to-stride variability within the locomotor pattern in a speed-dependent manner as it has been previously demonstrated for deficient visual and vestibular locomotor control [15,16]. Furthermore, we aimed to determine those gait alterations that distinguish neuropathic subjects with and without a history of accidental falls.

2. Methods

2.1. Subjects and procedures

Eighteen patients with a significant PN of the legs and feet (70.7 ± 2.4 years, 6 females) participated in the study. The etiologies of PN included type 2 diabetes ($n = 10$), vitamin B12 deficiency ($n = 2$), ethyl toxicity ($n = 2$) and idiopathic PN ($n = 4$). All patients presented the following criteria for a distal, symmetric sensorimotor PN [17]: (1) symmetric symptoms corresponding to PN; (2) a physical examination consistent with PN (symmetrically absent or relatively decreased Achilles reflexes, decreased distal lower extremity sensation that improved proximally); (3) electro-diagnostic evidence corresponding to a symmetric distal, sensorimotor polyneuropathy by the presence of one or more abnormalities in the peroneal motor and sural responses. All subjects exhibited absent or decreased amplitude sural responses ($<6\ \mu V$) and peroneal motor responses with a decreased amplitude (<2 mV) and/or conduction velocity (<41 m/s). The neurological examination revealed that no pareses of the hip extensors or flexors were present in the PN cohort. The mean duration of symptoms was 4.5 ± 1.1 years. Exclusion criteria were cognitive impairment, motor weakness or comorbidities affecting postural and gait abilities. The history of falls in the PN cohort was obtained based on self-reports during the baseline evaluation. Patients were subsequently categorized as a "faller" (i.e. history of falls since the onset of symptoms) or a "non-faller" (i.e. no history of falls since the onset of symptoms). Additionally, their subjective level of postural stability was assessed with the Falls Efficacy Scale-International (FES-I) [18]. Eighteen age- and gender-matched healthy subjects (HS) (70.4 ± 2.4 years, 6 females) formed the control group (Table 1). All subjects gave their written informed consent prior to the experiments. The study was approved by the local ethics committee.

Gait analysis was performed using a 6.7-m-long pressure-sensitive carpet (GAITRite®, CIR System, Havertown, USA) with a sampling rate of 120 Hz. Walking patterns were recorded during three different locomotion speeds (i.e., slow (SWS), preferred (PWS), and maximal walking speed (MWS)) with eyes open and during preferred walking with eyes closed (EC)).

2.2. Data and statistical analysis

Walking velocity and eight additional standard gait cycle parameters (i.e., cadence, base width, stride length, stride time, double support time, double support time percentage, swing time percentage, and stance time percentage) were analyzed for each trial and leg separately. Furthermore, the variability magnitude of stride time, stride length and base width was analyzed using the coefficient of variation (i.e., $CV[\%] = (\sigma/\mu) \times 100$, with standard deviation σ and mean μ).

Descriptive statistics are reported as mean ± SE. Significant differences in the background characteristics of the study cohorts and in individual walking speeds were analyzed with a one-way ANOVA. To evaluate the effects of walking speed on each gait parameter a Mixed Effects Model for repeated measures was used. A separate model was applied for each gait parameter, with the gait parameter as dependent variable and leg side, group, walking speed and the interaction term group x speed as independent variables. Post hoc analysis was carried out using a Bonferroni post hoc test. A corresponding statistical analysis was used to evaluate the effects of walking with eyes open vs. eyes closed on each gait parameter. A binary logistic regression analysis was performed to identify those gait measures that were significantly related to the fall status of patients (faller vs. non-faller) after adjusting for age and gender. Results were considered significant if $p < 0.05$. Statistical analysis was performed using SPSS (Version 20).

3. Results

The walking speed results are given in Table 1. Mixed Effects Model results are presented in Table 2. Detailed descriptive statistics are available in the supplementary data.