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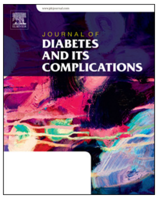

Step length after discrete perturbation predicts accidental falls and fall-related injury in elderly people with a range of peripheral neuropathy ☆,☆☆,★

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ABSTRACT

Aims: Distal symmetric polyneuropathy increases fall risk due to inability to cope with perturbations. We aimed to 1) identify the frontal plane lower limb sensorimotor functions which are necessary for robustness to a discrete, underfoot perturbation during gait; and 2) determine whether changes in the post-perturbed step parameters could distinguish between fallers and non fallers.
Methods: Forty-two subjects (16 healthy old and 26 with diabetic PN) participated. Frontal plane lower limb sensorimotor functions were determined using established laboratory-based techniques. The subjects' most extreme alterations in step width or step length in response to a perturbation were measured. In addition, falls and fall-related injuries were prospectively recorded.
Results: Ankle proprioceptive threshold (APrT; $p = .025$) and hip abduction rate of torque generation (RTG; $p = .041$) independently predicted extreme step length after medial perturbation, with precise APrT and greater hip RTG allowing maintenance of step length. Injured subjects demonstrated greater extreme step length changes after medial perturbation than non-injured subjects (percent change $= 18.5 \pm 9.2$ vs. 11.3 ± 4.57; $p = .01$).
Conclusions: The ability to rapidly generate frontal plane hip strength and/or precisely perceive motion at the ankle is needed to maintain a normal step length after perturbation, a parameter which distinguishes between subjects sustaining a fall-related injury and those who did not.

1. Introduction

The World Health Organization noted a prevalence of Diabetes Mellitus (DM) of 171 million people in the year 2000 and predicted an increase to 366 million by 2030. The disease is generally more common in developed countries. For example, the lifetime risk of developing diabetes in the United States for those born in year 2000 is about 40% for women and 30% for men (Narayan et al., 2003).

It is understood that type 2 DM leads to early mortality, as well as retinopathy, nephropathy, neuropathy and accelerated macro vascular diseases (Nathan, 1993). Therapies that normalize glycemia are thought to prevent generation and/or delay progression of such complications (Nathan, 1995). The most common non-pharmacologic approaches to improve glycemic control are weight loss and exercise (Ismail-Beigi, 2012). Exercise provides an additive effect when combined with caloric restriction (Association, 2012) and it has been recommended that patients should engage in at least 150 min of moderate-intensity aerobic exercise per week (Association, 2012). Most exercise regimens feature walking, and it has been shown that a walking program improves the metabolic profile of patients with type 2 DM (Sung & Bae, 2012).

Although prevalence varies, peripheral neuropathy (PN) is common in patients with type 2 DM. A 2007 French study found an 11% prevalence of PN in adults with DM (Wu et al., 2007), while a 1999–2000 United States study noted a 28.5% prevalence in those with DM aged 40 years and older (Gregg et al., 2004). Importantly, diabetic PN reduces sensory and motor neuron excitability which in turn leads to coarsened proprioceptive thresholds and distal muscle atrophy (Narici, Maganaris, & Reeves, 2005), resulting in prolonged muscle response latencies. These patho-physiological changes adversely affect motor control and alter balance (Allet et al., 2012a) and gait (Allet et al., 2012a; Allet et al., 2008), markedly increasing risk for falls and fall-related injuries (Wallace et al., 2002; Allet et al., 2009). Therefore older patients with PN are at increased risk for a fall-related injury, while endeavoring to improve their health by pursuing a walking program.

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Falls occur most frequently among older subjects with, and without, neuropathy while walking on uneven surfaces (Allet et al., 2009; DeMott et al., 2007). Given the importance of walking to the health of patients with Type 2 DM, there is a need to identify the lower limb sensorimotor functions essential to cope with perturbations and avoiding falls. To date few studies have investigated the relationship between lower limb neuromuscular function and surface perturbations and no study has evaluated the relationships between lower limb sensorimotor function and a discrete, unanticipated perturbation. To address this we performed laboratory-based evaluations of lower limb frontal plane sensorimotor function using established techniques, and then observed older subjects with a spectrum of peripheral neurologic function due to diabetes mellitus respond to an unexpected, discrete perturbation during stance phase of gait by means of a specifically designed shoe (Kim & Ashton-Miller, 2012). The shoe challenged lateral (i.e., frontal plane) control, which is relevant given the greater injury potential of lateral falls in older adults (Maki, Holliday, & Topper, 1994; Cummings & Nevitt, 1994). The subjects were then followed prospectively to record falls and fall-related injuries.

The ideal response to a discrete perturbation was defined as per Reeves et al. (ref) who argue that a robust biologic system changes its behavior minimally in response to a perturbation. This means that the error between the disturbed and undisturbed motions should be minimal and converge to the undisturbed pattern in a short time interval following a perturbation. Therefore, the objectives of the present study were to: 1) Identify the specific frontal plane lower limb sensorimotor functions necessary for robustness (minimal change in response) to a discrete, underfoot perturbation during gait; and 2) Determine whether post-perturbation step parameter changes could distinguish between those who sustained falls and fall-related injuries, and those who did not, during one year of follow-up. Given prior work (Allet et al., 2012a; Allet et al., 2012b) we hypothesized that Hip motor function (specifically, rate of torque Generation), ankle proprioceptive threshold (APrT) and the ratio of the former to the latter would be the predominant influences on post-perturbation step characteristics (H1). We further hypothesize that most extreme post-perturbation step length and/or step width (of the four analyzed) would identify subjects who were not robust to perturbation and distinguish between subjects who fell and/or sustained a fall-related injury and those who did not (H2).

2. Materials and methods

2.1. Subjects

Forty-two subjects (16 healthy old and 26 with diabetic PN) aged between 50 and 85 years and with a weight lower than 136 kg, were recruited from the University of Michigan Orthotics and Prosthetics Clinic, Endocrinology Clinic, and the Older Americans Independence Center Human Subjects Core. The PN subjects had disease severity that ranged from minimal to moderate severity so that when they were included with the older subjects without PN, a spectrum of lower limb sensorimotor function within the study population was assured. To participate in the study, subjects had to be able to walk household distances without any assistance and without any assistive device. They further had to present strength of ankle dorsiflexors, invertors, and evertors at least anti-gravity (grade 3 by manual muscle testing). Full details of inclusion and exclusion are available (Allet et al., 2012a). In general, these criteria eliminated subjects with upper motor neuron dysfunction, vestibular and visual conditions that would interfere with stability, limiting pain, falls within the prior 6 months, or joint replacement within the prior year.

The entrance evaluation involved a physical examination during which in- and exclusion criteria were verified. For the subjects with diabetes, the presence of PN was confirmed by symptoms (subject report of altered distal lower limb sensation), signs (Michigan Diabetes Neuropathy Score > 10) (Richardson, 2002; Strotmeyer et al., 2010) and fibular motor nerve conduction studies. Bilaterally abnormal fibular nerve conduction studies (absent or amplitude <2 mV and/or latency >6.2 ms and/or conduction velocity <41.0 m/s, stimulating 9 cm from the recording site over the extensor digitorum brevis distally, and distal to the fibular head proximally) were essential for inclusion as PN (Allet et al., 2012a). Subjects without diabetes met the same inclusion and exclusion criteria except that they had no symptoms or signs of neuropathy, and had normal fibular motor nerve conduction studies.

The study protocol was approved by the institutional review board. Written informed consent was obtained from all participants.

2.2. Evaluation of lower limb sensorimotor function

2.2.1. Frontal Ankle proprioceptive threshold (APrT)

The subjects stood with the foot and ankle being tested in a 40 × 25-cm cradle that rotated in the frontal plane (inversion and eversion). The cradle was rotated by a servomotor equipped with an 8000 line rotary encoder (Aerotech 1000 servomotor; Aerotech, Inc, Pittsburgh, PA). The subject responded to the direction of the rotation with a hand-held joystick. Four blocks of 25 trials (randomly, 10 eversion, 10 inversion, and 5 dummy trials) were presented. Each block was interspersed with 2- to 5-min rest intervals. The outcome measure was the APrT, defined as the smallest rotational displacement of the ankle that a subject could reliably detect with 100% accuracy. The sum of the inversion proprioception threshold and eversion proprioception threshold was used for further analysis (Son, Ashton-Miller, & Richardson, 2009).

2.2.2. Ankle strength

Ankle muscle strength (maximum voluntary contraction; MVC and rate of torque Generation; RTG) was tested while subjects stood on the test foot on a force plate (OR-6; Advanced Mechanical Technology, Inc.) while touching hand rails.

To assess the MVC, subjects shifted their center of gravity as far laterally under their foot as possible and lifted their hands from the rails for 3 s. The test was repeated 3 times for the lateral margin of the foot (maximum voluntary inversion) and repeated for the medial margin of the foot (maximum voluntary eversion).

To measure ankle RTG, the subjects stood on the test foot on the force plate and moved the center of ground support reaction from the lateral margin of the foot to the medial margin as quickly as possible and then back again to the lateral margin, as previously described. Three trials, each trial with 5 medial–lateral movements, were performed (Allet et al., 2012a).

2.2.3. Hip strength

Hip abduction and adduction (MVC) and (RTG) in the frontal plane at the hip were measured with a custom whole-body dynamometer (BioLogic Engineering, Inc.). The subject lay supine on a horizontal bench with the pelvis and upper body immobilized with adjustable harness straps, and the limb being tested was secured with straps against a lever, which allowed all measurements to be made in a gravity-free plane. During maximum voluntary strength tests, the subjects progressively increased their isometric effort to their maximum over a count of 3 s, held it for 2 s, and relaxed. To quantify the rate of isometric strength development, the subjects increased their effort as rapidly as possible for 3 s. Three trials were performed with 1-min rests between trials. The subjects had a real-time visual display of the force generated to allow them to evaluate their efforts (Allet et al., 2012a).

2.2.4. Perturbed gait analysis

Subjects were equipped with a specific pair of shoes with electronically controlled linear actuators (ModelPQ-12, Firgelli Technologies, Inc., Victoria, BC, Canada). Each shoe deployed a small