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The relationship between frontal plane gait variability and ankle range of motion in older persons with neuropathy

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Abstract

Objective—To explore the relationship between frontal plane ankle range of motion (ROM) and frontal plane control during gait, as determined by step width variability (SWV) and range (SWR), among older persons with peripheral neuropathy (PN).

Design—Observational study of 39 older persons with PN. Demographic and clinical data, including measures of ankle ROM and PN severity, and spatiotemporal gait measures were obtained. Correlation and multivariate analyses were used identify relationships between measures of ankle ROM and frontal plane gait variability.

Results—Significant negative correlations were identified between frontal plane ankle ROM (inversion + eversion), and SWV ($r = -0.344$; $p = 0.032$) and SWR ($r = -0.386$, $p = 0.015$). Multivariate analyses showed that the relationship between ankle ROM and SWV weakened in the presence of PN severity, with ROM and PN severity both demonstrating trends toward independent associations with SWV ($p = 0.086$ and 0.083 , respectively; adjusted $r^2 = 0.145$). However, ankle ROM demonstrated a stronger association with SWR than did PN severity ($p = 0.043$ and 0.098 , respectively; adjusted $r^2 = 0.169$).

Conclusion—Increased frontal plane ankle ROM is associated with decreased variability in frontal plane foot placement during gait among older persons with PN, a population at high risk for falls.

Keywords

Neuropathy; Gait; Range of Motion; Articular; Rehabilitationary

INTRODUCTION

Peripheral neuropathy (PN) is a common disorder in older adults¹ that impairs distal lower extremity sensory and motor function leading to postural instability, particularly in the frontal plane. Accordingly persons with PN have demonstrated, as compared to control groups, increased medio-lateral postural sway during bipedal stance,² decreased stability during unipedal stance,³ impaired ability to recover from a lateral perturbation during

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unipedal stance,⁴ and increased gait variability in the frontal plane that correlates with PN severity.⁵ These findings are likely related to PN-associated impairments in ankle inversion/eversion proprioceptive thresholds⁶ and rate of strength development at the ankle.^{4,7} As would be expected, the presence of PN in older adults markedly increases risk for falls and fall-related injuries.^{8–10}

The effect of PN on frontal plane balance in older adults is of particular concern. Not only are lateral falls likely to cause fractures,^{11,12} but disordered frontal plane control during quiet standing^{13–15} and dynamic tasks^{16,17} has been found to discriminate between older persons with and without a history of falls or impaired balance. Efforts to reduce risk of hip fractures from lateral falls have even included the use of external cushioned hip protectors, which can decrease fracture rate¹⁸ but are inconsistently worn in the at risk population.^{19,20} Given these findings, and the fact that the majority of fall-related injuries occur during ambulation,^{8,10,21} continued exploration of frontal plane instability during gait is warranted.

Previous work has demonstrated that the most effective²² and efficient²³ manner of controlling center of mass frontal plane motion during gait is by modifying step width. Moreover, clinical interventions thought to stabilize patients with PN (a cane, touch of a lateral vertical surface and ankle orthoses) significantly decreased frontal plane gait variability in a group of older PN subjects walking under challenging circumstances.²⁴ Given these findings, it appears that increased variability of step width during gait is consistent with impairment in frontal plane stability, or greater effort to control the center of mass in the frontal plane, or both.²⁵

Therefore we explored the relationship between frontal plane ankle range of motion and frontal plane gait variability in a group of older persons with PN. Variability was defined by the standard deviation of step width (SWV), and also by step width range (SWR), a measure of the difference between the greatest and least step widths. This latter measure is not commonly utilized in scientific work because it includes “outlier” data points. However this measure was included because a single aberrantly wide or narrow step may lead to, or result from, a loss of balance while walking, and so such aberrant steps may be of particular interest. We hypothesized that increased frontal plane range of motion (ROM) at the ankle in older persons with PN would be associated with decreased SWV and SWR, consistent with improved frontal plane control in walking.

METHODS

Subjects

Subjects were recruited from the University of Michigan Electrodiagnostic Laboratory and the Physical Medicine and Rehabilitation Outpatient Orthotics and Prosthetics Clinic, and participated in a previous study investigating the effect of interventions on gait variability.²⁴ All patients underwent history, physical examination and electrodiagnostic testing. The project was given approval by the University of Michigan Institutional Review Board and all subjects gave written informed consent.

Inclusion criteria were: age between 45 and 80 years, ability to speak and understand English and ability to ambulate household distances without an assistive device. Subjects also met criteria for a distal, symmetric sensorimotor PN by the presence of: 1) symmetric symptoms consistent with PN; 2) a physical examination consistent with PN (symmetrically absent or relatively decreased Achilles reflexes, decreased distal lower extremity sensation which improved proximally); 3) electrodiagnostic evidence consistent with a distal symmetrical, sensorimotor polyneuropathy in that one or more abnormalities were seen in the peroneal motor and sural responses. All subjects demonstrated sural responses that were

absent or of decreased amplitude (< 6 microvolts) and peroneal motor responses that were of decreased amplitude (< 2.0 millivolts) and/or conduction velocity (< 41.0 meters/second). The physical examination included determining the Michigan Diabetes Neuropathy Score (MDNS) which was used as a clinical measure of PN severity, and is a 0 to 46 point scale (higher score reflecting more severe PN) that correlates well with more extensive neuropathy staging scales.²⁶

Exclusion criteria were: subject report of abnormal vision despite correction; inability to follow verbal commands; weight greater than 136 kilograms (300 pounds); evidence on physical examination of central neurologic dysfunction; musculoskeletal abnormality such as severe scoliosis or amputation.

Ankle range of motion (eversion and inversion) was determined prior to gait testing using a standard goniometer by an experienced physical therapist or physiatrist. Subjects were measured while seated with the hips and knees flexed at 90 degree. The ankles were moved passively to demonstrate the movements of ankle inversion and eversion to the subjects. Then the subjects inverted, or everted, their ankles to the greatest extent possible upon request. A goniometer was then placed with the stationary arm on the anterior longitudinal midline of the leg and the alternate arm on the dorsum of the foot parallel to the lateral aspect of the second metatarsal.²⁷ To determine dorsiflexion the same procedure was followed but with the goniometer arms placed in the lateral midline of the leg and parallel to the fifth metatarsal. Each motion was determined twice and the mean of the two measurements used in data analysis.

Subject preparation and experimental apparatus

These methods have been used in previous work and are described in greater detail elsewhere.^{5,24} The subjects wore flat-soled athletic shoes supplied by the laboratory and were allowed five minutes to accommodate to them. The subjects were placed in a safety harness secured to an overhead track. The harness suspension was adjusted so as to prevent the knees from coming into contact with the floor when the subject hung unsupported. For all trials the subjects were instructed to walk at their own pace, as if they were “walking to mail a letter.” The subjects performed 10 trials (two lengths of the walking surface = one trial) on a smooth well lit, 10m surface. Kinematic data were obtained with optoelectronic markers (infrared-emitting diodes) placed 5 cm apart on a malleable aluminum strip (10 cm X 1.5 cm) inserted under the tongue of each shoe. The top marker was located anterior to the center of the malleoli. A marker was also placed on a belt in the midline at the level of the umbilicus. Two foot switches, each a force-sensing resistor, were placed underneath the insole of each shoe. One switch was placed under the first metatarsophalangeal joint and the other beneath the calcaneus. Double support was defined as the period of time in the gait cycle during which at least one switch inside each shoe was activated. Kinematic data were measured at 100 Hertz (Hz) using an optoelectronic camera system; (Optotrak 3020; Northern Digital Corp, 103 Randall Dr Waterloo, ON N2V 1C5, Canada) toward which the subject walked within the boundaries of the walkway.

Analysis of gait and kinematic data

The kinematic data were processed using a custom algorithm to quantify step width, step length and walking speed. Speed was calculated by taking the time derivative of the waist marker during what was defined as the “comfortable gait speed” interval. This interval was found by excluding data taken when the waist velocity was less than 85% of the maximum velocity for that trial. This was done so as to eliminate steps taken while the subject accelerated to and decelerated from the comfortable gait speed. Similarly, the other gait parameters were only included in the analysis during this interval.

Statistical analysis

Statistical analysis was performed using SPSS version 14.0 (SPSS Inc, 233 Wacker Dr, 11th floor Chicago IL 60606). The standard deviation of step width served as the SWV for each subject, and the difference between the greatest and least step widths (considering all trials) served as the SWR for each subject. The means and standard deviations of the clinical variables were determined. The relationships between relevant gait variables, ankle ROM and clinical variables were analyzed using Pearson correlation. Clinical variables that significantly correlated with SWV and SWR were used as predictor variables and entered into multiple regression analysis, using SWV and SWR as outcome variables. A p value of less than 0.05 was considered significant.

RESULTS

Thirty-nine older persons with PN [mean age $\pm$ standard deviation = 64.7 ± 9.5 years; 18 (46.1%) women] were studied. There were no gender based differences in the clinical variables (all p values > 0.20). Demographic, clinical and kinematic data are presented in Table 1.

Table 2 demonstrates a correlation matrix of ankle ROM and gait variables of interest. Significant negative correlations were identified between frontal plane ankle ROM and SWV, as well as SWR. PN severity, a potential confounder, also correlated with SWV and SWR ($r = 0.341$; $p = 0.033$). No other significant relationships between clinical variables and measures of lateral gait variability were identified. Importantly, dorsiflexion range of motion did not demonstrate a significant relationship with either SWV or SWR. Multivariate analysis showed that the relationship between ankle ROM and SWV weakened in the presence of PN, with ROM and PN both demonstrating trends toward independent associations with SWV ($p = 0.086$ and 0.083 , respectively; adjusted $r^2 = 0.145$). However, using SWR as the outcome variable of interest, ankle ROM demonstrated a stronger association with SWR than did PN severity ($p = 0.043$ and 0.098 , respectively; adjusted $r^2 = 0.169$).

DISCUSSION

The major finding in this study is the identification of a negative relationship between frontal plane ankle ROM and two measures of frontal plane gait variability, indicating that as ankle ROM increased gait variability decreased. Therefore, the data suggest that increased ankle inversion and eversion are associated with improved frontal plane control of foot placement during gait on a smooth surface. In contrast dorsiflexion ROM at the ankle was not found to be associated with frontal plane gait variability, suggesting that the relationship found with ankle inversion/eversion is not explained by a global increase in ankle or lower extremity flexibility but, rather, specific to flexibility in the frontal plane. This was particularly true for the association between ankle ROM and SWR, suggesting that frontal plane ankle ROM is an independent predictor of SWR. This finding may be more clinically relevant than a relationship with SWV given that SWR includes extreme steps that may be precursors to falls.

Other work that suggests that frontal plane motion at the ankle is necessary for optimal frontal plane balance adds plausibility to the findings. Ankle inversion and eversion have been found to assist in controlling medial-lateral balance²⁸ and in correcting lateral foot placement errors during unperturbed gait.²² The subtalar joint has also been found to be the dominant influence in the control of frontal plane balance during quiet standing with a narrow base²⁹ and to influence change of direction while walking, particularly when there is no early warning that a directional change is to occur.³⁰ Finally, older persons with a history

of falls have shown reduced ankle range of motion as compared to non-fallers,³¹ and positive correlations between frontal plane (and total) ankle range of motion and scores on the gait subtest of the Performance Oriented Mobility Assessment tool have been identified.³² Despite this supporting evidence a cause and effect relationship between frontal plane ankle range of motion and gait variability cannot be inferred from the data presented, chiefly because all possible confounders have not been accounted for. For example ankle strength, which was not quantified, might be responsible for increased ankle range of motion and decreased gait variability. In addition, the temporal relationship between the two variables was not clarified by this study and it is possible that increased frontal plane gait variability leads to loss of confidence, with a resultant decreased frequency of ambulation, which leads to reduced ankle range of motion.

In addition to these uncertainties the study itself has features that limit the strength of the conclusions. Most notably, although there is biomechanical support for the use of SWV and SWR as surrogates for, or markers of, frontal plane control it is not fully accepted that these measures reflect stability during gait. For example, Maki identified stride to stride variability in speed as the most important predictor of falls in a group of older persons,³³ and Hausdorff et al. have identified increased step time variability to be associated with a variety of functional and pathologic conditions.^{34–36} Moreover, in other research SWV did not differ in older persons with and without a history of falls.^{37, 38} Another concern is that two different examiners determined ankle ROM. Although both examiners were experienced clinicians inconsistency between them is possible. However it does not seem likely that any systematic bias was introduced given that the gait testing was always performed after the ankle ROM was determined, and the results of that testing were not immediately available. Therefore the examiners were, in effect, blinded to the results of gait testing. Lastly, the population of older persons with PN tested may not accurately represent the overall patient population of older persons with PN, given that individuals who volunteer for a gait study may be less sedentary, or more concerned about their gait, than the aggregate population.

In conclusion older persons with PN who have greater inversion/eversion ROM at the ankle appear to have improved frontal plane control during gait, as evidenced by decreased SWV and SWR. This effect appears to be, for the most part, independent of PN severity. If future clinical studies find that increasing ankle inversion/eversion ROM is possible in older persons with PN, and leads to improved frontal plane control during ambulation, such treatment will represent an addition to the clinician's repertoire for improving gait function in this challenging population, for whom there is often no direct treatment of the primary neurologic disorder.

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Table 1

Demographic, clinical and kinematic data (n = 39 subjects; 18 women)

Variable	Mean	Standard Deviation	Range
Age (years)	64.7	9.5	47 – 83
Body Mass Index	31.8	6.8	14.9 – 48.8
Michigan Diabetes Neuropathy Score	17.7	5.6	8 – 34
Step Width (mm)	180.0	31.3	134.0 – 258.3
Step Width Variability (mm)	35.0	8.4	20.2 – 51.5
Step Width Range (mm)	161.3	40.3	78.7 – 243.2
Ankle ROM (inversion + eversion in degrees)	41	12	18 – 68
Ankle ROM (dorsiflexion in degrees)	93	9	50 – 107.5

* Standard Deviation

Table 2
Pearson correlations, with accompanying p values, between ankle ROM and gait variables

	Ankle ROM (Dorsiflexion)	Michigan Diabetes Neuropathy Score	Step Width Variability	Step Width Range
Ankle ROM (Inversion + Eversion)	0.411; p = 0.010	-0.254; p = 0.119	-0.344; p = 0.032	-0.386; p = 0.015
Ankle ROM (Dorsiflexion)	–	-0.136; p = 0.415	-0.134; p = 0.134	-0.192; p = 0.248
Michigan Diabetes Neuropathy Score	–	–	0.346; p = 0.031	0.341; p = 0.033
Step Width Variability	–	–	–	0.922; p < 0.001