# Sharpening the Tandem Walking Test for Screening Peripheral Neuropathy

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**Objective:** Few tests of functional motor behavior are useful for rapidly screening people for lower extremity peripheral neuropathy. The goal of this study was to improve the widely used tandem walking (TW) test.

**Methods:** We tested "normal" (control) adult and ambulatory patients with peripheral neuropathy (PN) with their eyes open and eyes closed while they performed TW on industrial carpeting in sock-covered feet. Each subject wore a torso-mounted inertial motion unit to measure kinematic data. The data of subjects with PN also were compared with historical data on patients with vestibular impairments.

**Results:** The normal and PN groups differed significantly on TW and on the number of steps completed. PN and vestibular impairments data also differed significantly on both visual conditions. Kinematic data showed that patients with PN were more unstable than normal patients in the group. For the number of steps taken during the eyes open condition, receiver operating characteristic (ROC) values were only 0.81 and for the number of steps taken during the eyes closed condition, ROC values were 0.88. Although not optimal, this ROC value is better. Sensitivity and specificity at a cutoff of two steps were 0.81 and 0.92, respectively, and at a cutoff of three steps were 0.86 and 0.75, respectively. ROC values for kinematic data were <0.8, and when combined with the ROC value for the number of steps, the total ROC value did not improve appreciably.

**Conclusions:** Although not ideal for screening patients who may have PN, counting the number of steps during TW is a quick and useful clinical test. TW is most sensitive to patients with PN when they are tested with eyes closed.

**Key Words:** balance testing, clinical examination, neurology testing, sensitivity and specificity, tandem gait

Balance tests are often cited as being useful for screening people suspected of having vestibular impairments (VI),[1,2] but these tests also may be useful for screening patients with neurological impairments,[3–5] and computerized posturography systems that test standing balance are commercially available. Some patients with peripheral neuropathy (PN) are impaired when screened with computerized dynamic posturography testing but not with the same pattern as patients with VI.[6–8] Although some primary care physicians screen patients for PN using monofilament testing, this type of testing is designed to screen for only small-fiber neuropathy. Balance testing may be sensitive to large-fiber neuropathy and small-fiber neuropathy and may provide a more functional indicator of balance skills. The cost of a computerized balance testing system and the size of the equipment preclude using such systems in many clinics[9]; therefore, a simple measure of walking balance may be useful for primary care physicians to augment their screening regimens, particularly for patients who may be at risk for falls.

## Key Points

- To screen people for lower extremity peripheral neuropathy, the tandem walking test is most sensitive when performed with eyes closed.
- The best measure is the number of consecutive steps taken out of 10.
- Kinematic measures do not improve the receiver operator characteristic values of the test.

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Various versions of the tandem walking (TW) test[10,11] have been in use for many years.[12] TW was developed originally for use on narrow rails with the patient's eyes open (EO), but it became standardized with eyes closed (EC).[11] Longridge and Mallinson reported that <30% of patients with VI or patients without VI could perform five steps of TW with EC.[13] Patients with VI have impaired performance compared with those without VI.[14]

Performance on several variations of TW declines slightly with aging.[15–18] Despite its widespread use, no studies have determined whether TW actually distinguishes patients with PN or sensory ataxia from "normal" (control) patients.

To determine how people with PN perform on this quick and inexpensive test, we compared the scores of control adults with patients with PN. The usual measure of TW is the number of steps taken. To learn more about performance on TW, we also complemented the number of steps by assessing trunk kinematics, measured with sophisticated instrumentation. We did not expect that clinicians would have this kind of sophisticated equipment planned to determine whether more information about kinematics would be useful for understanding the qualitatively observable responses.

## Methods

### Subjects

Data for our study were collected between October 2009 and December 2010. Controls were recruited from staff members and visitors to our laboratory and were screened with a brief health history and tested with Dix-Hallpike maneuvers, head shaking in yaw rotations, and head impulse tests to exclude vestibular disorders.[14] No subjects had joint replacements, were missing any toes, had deformities of the toes, or had less-than-functional range of motion in all joints; no subjects complained of pain while walking; and all of the subjects were ambulatory without the use of canes or other gait aids. All of the subjects wore comfortable clothes and performed all of the tests without shoes, but for proper hygiene, all of the subjects wore socks. Subjects gave written informed consent before participating. This study was approved by the institutional review board for human subjects research at the corresponding author's institution.

Subjects with PN were first identified from patient records. All subjects with PN had previously been diagnosed by board-certified neurologists with large (n = 5), small (n = 7), or mixed large and small fiber neuropathy (n = 9), based on the neurologist's clinical examination, which may have included electromyography testing. We were unable to determine the length of illness for subjects with PN. None of the subjects had developed their disease states within 1 month of testing. Details of inclusion/exclusion criteria are given in Table 1.

**Table 1. Inclusion and exclusion criteria**

| Inclusion criteria | Exclusion criteria |
|---|---|
| Ambulate independently | Hip, knee, or ankle joint replacements |
| Controls: no sensory losses, no balance complaints | Central neurological damage |
| Diagnosis of lower extremity peripheral neuropathy | Significant musculoskeletal limitations |
| Functional vision (at least 20/40) with corrective lenses | No use of walker or cane |
| Fluently speaking English | History of vestibular disorder |
| | Indication of vestibular disorder based on screening |
| | No psychiatric diagnoses or cognitive limitations |

### Instrumentation

During testing, each subject wore a lightweight vest with an inertial motion sensor (IMU; Xsens North America Inc, Los Angeles, CA), 5.25 × 3.75 × 2 cm, weight 28.3 g, centered on the back at the mid-thoracic level. The IMU was used to measure kinematic data, as described below.

### Tests

Tests were administered by one of three technicians with 7 to 25 years of experience performing vestibular and balance testing. Technicians were unaware of the subjects' diagnoses. Interrater reliability for these tests had been established in tests of normal subjects and patients with VI.[14] For all of the measures, the interrater reliability was 0.94 to 0.99.

Subjects were asked to walk 10 steps, heel-to-toe, without spaces between the steps. They performed trial 1 with EO and trial 2 with EC. The technicians recorded the maximum number of correct consecutive steps, for a maximum of 10. Errors included taking a side step, making a space between the feet, and opening the eyes during the EC condition. Subjects were given one trial per condition, for a total of two trials. To avoid a learning effect, repeated trials were not used. The EO condition was always given first. Staff members provided safety guarding during all of the tests that were given in a quiet room with industrial carpeting.

### Kinematic and Behavioral Analyses

After testing, raw kinematic data were reduced by technical staff who were blinded to the subjects' groups and had more than 15 years of experience working with kinematic data. For kinematic analyses, the following root mean square values of the IMU variables for the trunk segment were quantified and used for further analysis: resultant acceleration (TAR), angular velocity about the roll axis (TRV), angular velocity about the pitch axis (TPV), and angular velocity about the yaw axis (TYV).

### Statistical Analyses

To describe differences in the dependent measures, multilevel statistical techniques[19] were used with a separate

model fitted to each dependent variable. Within each model, within-subjects and between-subjects effects were tested. Interaction effects were included and tested in each model. A likelihood ratio statistic that follows a chi-square distribution was used to compare changes in eye conditions between groups and adjustments were made for multiple comparisons. Tests of the number of steps were adjusted for age. $P < 0.05$ was considered statistically significant.

Receiver operating characteristic (ROC) analysis is a type of statistical analysis that developed from signal detection theory[20] and is used in medical research to determine the discriminatory power of a clinical test. We subjected the dependent measures of the number of steps taken and the kinematic measures to ROC analyses. An ROC value >0.95 is considered excellent and means that the test has a high discriminative value; an ROC value of 0.50 is chance and means that the test has no discriminative value at all. When the ROC analysis is good to excellent, then sensitivity to detecting patients with PN and specificity to detecting controls can be calculated for different cutpoints (eg, different values of the test). To determine whether any test is useful in identifying people with PN and to determine the optimal cutpoint on each test, we performed logistic regression and ROC analyses and provided corresponding sensitivity and specificity values for various cutoffs. All of the statistical analyses were performed using SAS version 9.3 (SAS Institute, Cary, NC).

## Results

The final sample included 61 controls and 21 subjects with PN (Table 2). As indicated in Table 2, subjects with PN were significantly older than the controls and were recruited from patients seen in local hospitals staffed by neurologists at the Baylor College of Medicine.

Subjects with PN took significantly more consecutive steps with EO than with EC ($P < 0.0001$). Controls took significantly more steps than subjects with PN under EO ($P < 0.0001$) and EC ($P < 0.0001$) conditions (Table 3). Of the 21 subjects with PN, only one subject slipped and had to be steadied by a staff member and another subject needed contact guarding on every step. No other subjects were assisted by staff during test administration. To determine whether these patients differed from other patients with balance disorders, we also compared these data with data from 27 subjects with unilateral peripheral vestibular weakness from a previously published study on patients with VI.[14] The groups did not differ significantly by age. *t* Tests showed significantly fewer steps taken by subjects with PN than those with VI under EO ($P < 0.01$) and EC conditions ($P < 0.001$; Table 3).

**Table 2. Demographic details of study sample**

| Group | Mean age, y | No. per sex |
|---|---|---|
| Controls | 49.6 (16.0, 23.3–77.0) | F: 30, M: 31 |
| Patients with PN | 60 (12.4, 30.6–74.3) | F: 8, M: 13 |

*PN, peripheral neuropathy.*

**Table 3. Tandem walking (adjusted mean [median, ranges])**

| Patients' condition | EO | EC |
|---|---|---|
| Controls | 9.25 (10, 3–10) | 5.76 (5, 1–10) |
| PN | 5.74 (4, 0–10) | 2.07 (1, 0–6) |
| VI | 7.8 (8, 4–10) | 3.8 (4, 0–10) |

*Number of consecutive steps per condition for normal patients, patients with PN, and patients with VI. Age-adjusted tests showed that controls and subjects with PN differed significantly for each condition ($P < 0.0001$).*
*EC, eyes closed; EO, eyes open; PN, periperal neuropathy; VI, vestibular impairments.*

For the kinematic analyses, subjects without PN had significantly higher TRV, TPV, and TYV than the control group ($P < 0.001$), and regardless of group, subjects had significantly higher scores under EC than under EO conditions ($P < 0.001$). For TAR, the groups differed significantly ($P = 0.001$) and the conditions differed significantly ($P = 0.0001$). These results indicate that subjects without PN showed greater instability in all planes than the control group performing the TW with EC (Figs. 1 and 2).

ROC analyses of the number of steps comparing the control group to subjects with PN were moderate with EO (ROC 0.81, 95% confidence interval 0.70–0.93) and stronger with EC (ROC 0.88, 95% confidence interval 0.81–0.96). No clear cutpoint for EO could be found and the best cutpoint for EC was two steps (Table 4).

ROC analyses of the kinematic data for tests with EC were calculated, and then ROC values for kinematic data combined with the number of steps for tests with EC were calculated. All of the ROC values for kinematic data alone were low: TAR, ROC 0.67; TYV, ROC 0.651; TPV, ROC 0.608; TRV, ROC 0.561. When combined with the number of steps for the EC condition, ROC improved slightly: steps + TAR, ROC 0.886; steps + TYV, ROC 0.882; steps + TPV, ROC 0.885; steps + TRV, ROC 0.888.

## Discussion

TW is widely known and used by physicians, but it is not well understood or validated. We have shown that on an easily observed measure of behavior and the number of steps taken, patients with PN differed from controls. Many physicians routinely use the EO condition for TW. The ROC analyses indicate, however, that despite statistically significant differences between groups with EO, the EC condition is the better measure. The sensitivity and specificity analyses showed that not many steps are needed for the test. The optimal cutpoint was only two steps; thus, even in a small examining room, adequate space should be available for this test.

Kinematic measures are not as easily quantified but are also important to elucidate the performance of patients with

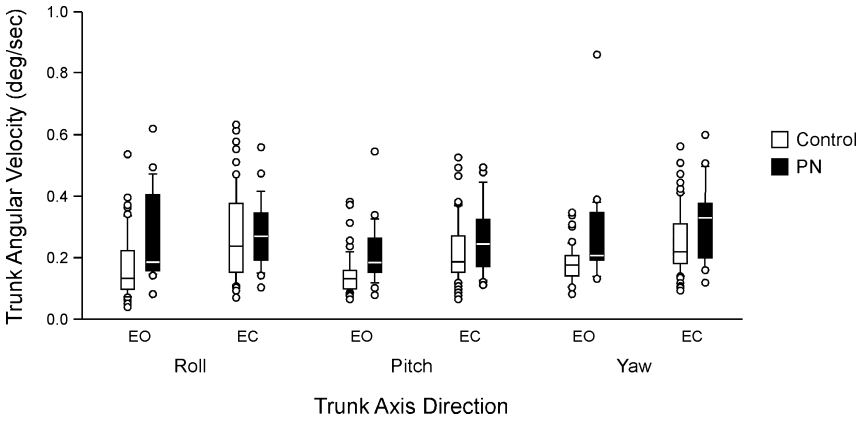


**Fig. 1. Trunk angular velocity by group and condition. Center horizontal bars are medians, rectangle ends are interquartile ranges, error bars are 10th and 90th deciles, and circles are outliers. EC, eyes closed; EO, eyes open; PN, peripheral neuropathy.**

PN. On all kinematic measures, patients with PN were more unstable than those in the control group. The greater stability of controls probably allowed them to take more steps than patients with PN; however, combining the kinematic scores with the number of steps in the ROC analyses improved the ROC for the EC condition only slightly—not enough to warrant the collection of kinematic data during routine clinical screening.

Nevertheless, the kinematic data from this study are useful for the physician. Some patients may have better innate motor skills than others. A patient may be able to perform more than two consecutive steps with EC using some unusual strategy, but that strategy may be reflected in abnormal kinematics. If a physician observes that the patient is using an unusual movement pattern to perform the test, then the physician should consider examining the problem further.

Patients with PN exhibit highly variable performance, depending on the subtype of PN, disease stage, and other health conditions; therefore, this relatively small study should be considered preliminary. Within the time period that we recruited subjects with PN, a larger sample was unavailable. Some patients declined to participate; other patients were excluded because they had joint replacements, were unable to walk unassisted (without gait aids), had additional neurologic diagnoses or had significant otologic or musculoskeletal problems that may have confounded data interpretation. We standardized footwear by having subjects remove their shoes but wear socks to maintain proper hygiene. Clinicians who habitually test patients in their shoes or in bare feet should keep this difference in mind when performing TW. Future work should include larger samples and use groups that do not differ by age.

This study did not use patients with any known history of stroke or essential tremor. These conditions are relatively common in neurology practice and may be seen in patients who present with balance impairments; therefore, the primary care physician who screens such a patient should take these problems into account when interpreting data from balance testing.

We compared the data collected in this study to data collected from patients known to have VI. The patients with PN

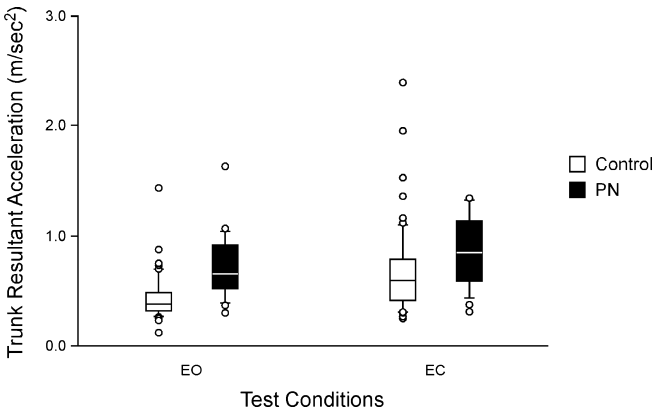


**Fig. 2. Trunk resultant acceleration by group and condition. Center horizontal bars are medians, rectangle ends are interquartile ranges, error bars are 10th and 90th deciles, and circles are outliers. EC, eyes closed; EO, eyes open; PN, peripheral neuropathy.**

**Table 4. Tandem walking: ROC analyses**

| No. steps | Sensitivity (to subjects with PN) | Specificity (to controls) |
|---|---|---|
| EO | | |
| 3 | 0.43 | 0.98 |
| 5 | 0.62 | 0.95 |
| 7 | 0.67 | 0.89 |
| 8 | 0.67 | 0.84 |
| EC | | |
| 2 | 0.81 | 0.92 |
| 3 | 0.86 | 0.75 |
| 5 | 0.95 | 0.46 |
| 7 | 1.0 | 0.38 |
| 8 | 1.0 | 0.28 |

*Sensitivity and specificity at several scores, controls, and subjects with PN. EC, eyes closed; EO, eyes open; PN, peripheral neuropathy; ROC, receiver operating characteristic.*

performed worse and patients with VI typically complained of vertigo. This additional information may help the primary care physician to determine the diagnosis or the need for specific specialty care referrals. These samples are relatively small and both patient populations are highly variable; therefore, these findings should be considered preliminary.

The use of ROC and of sensitivity/specificity analyses are important aspects of this study. Many reported tests show statistically significant differences between control and patient groups. Those differences may not be highly meaningful or important; however, patients and controls are not sufficiently different to be distinguished on testing. Tests are useful for screening only if the scores of the groups are so different that the tests are sensitive to the patient population of interest and specific to control subjects. This concept is especially important when the healthcare provider who administers the screening for PN is a nonspecialist, such as a physician who is not a neurologist or a nonphysician clinician such as a nurse or therapist.

At the cutoff of two steps, TW with EC has good sensitivity and specificity. Ideally, a test should have a high ROC value and high sensitivity and specificity, and with a larger sample, those values may have been different. TW used in combination with the rest of the clinical examination should be useful when identifying patients who may have PN and who may benefit most from more detailed diagnostic testing.

Balance testing in primary care is important for identifying deficits that may suggest underlying illness and for predicting subsequent levels of functional decline and even mortality.[21,22] In this regard, TW is valuable for the primary care physician because administering it takes only 30 seconds and requires no special equipment or extra space. It provides reliable data to facilitate further clinical decision making, such as the need for more detailed examination, specific testing, or referral to a specialty service such as neurology. If the physician has a positive finding, then referral to a specialty care physician, such as a neurologist, should be considered to obtain a definitive diagnosis. Diagnosis and treatment of balance disorders may improve patient functional abilities and quality of life, thereby reducing healthcare costs. Use of TW with EO for patients to understand the test and with EC for formal evaluation may aid in achieving those goals.

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