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An Exploration of Step Time Variability on Smooth and Irregular Surfaces in Older Persons with Neuropathy

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Abstract

Background—Increased step time variability, particularly on an irregular surface, has been associated with impaired mobility function and a variety of diseases. However the biomechanical necessity, or advantage, of increasing step time variability has not been identified.

Methods—We performed a secondary analysis of gait data previously obtained on 42 subjects age 50 or older with neuropathy who walked on smooth and irregular surfaces, the latter with and without three interventions (cane, ankle orthosis and wall touch) that provided frontal plane support.

Findings—Step time variability on smooth and irregular surfaces was most strongly associated with reduction in step length on the irregular surface as compared to the smooth. More specifically, the greater the decrease in step length on the irregular surface the greater the step time variability on both surfaces and the greater the increase in step time variability on the irregular surface. The increase in step length on the irregular surface afforded by the interventions coincided with a decrease in step time variability. The subjects did not simultaneously demonstrate increased step time variability and step width range on the irregular surface.

Interpretation—Among adults age 50 and older with neuropathy, increased step time variability is strongly associated with the need to shorten step length on an irregular surface. Therefore step time variability may be a marker for instability during single limb stance which necessitates rapidly placed, shortened recovery steps. Such steps may also offer the advantage of reducing extremes in lateral foot placement of the swing limb, and so assist in maintaining frontal plane stability.

Keywords

gait; neuropathy; variability

INTRODUCTION

An increasing volume of research suggests that a temporally irregular gait is associated with aging, falls and a variety of diseases. Increased temporal gait variability, often referred to as increased stride time or step time variability (STV), has been found in the healthy old as compared to the young[1] and is a feature of gait in persons with traumatic brain injury,[2] Parkinson's disease,[3] Alzheimer's disease,[4] affective psychiatric disorders[5] and peripheral neuropathy (PN) due to diabetes[6] and other causes.[7] Increased STV has also been found in older adults with a "cautious" gait of uncertain etiology,[8] and to be a marker for functional status and performance-based measures of function.[9] Finally, increased STV has been found to be associated with falls[10,11,12] and fall risk.[13]

There is also evidence that an irregular surface is an effective stimulus for increasing gait variability in a variety of clinical groups including healthy young and older women[14], healthy young and old of both genders[15] and two separate groups of older persons with PN.[6,16] Of greater importance, an irregular surface appears to accentuate differences in STV between groups of clinical interest, such as healthy old as compared to healthy young,[1] older women with and without PN,[7] older persons with PN with and without a history of falling in the previous year,[12] and older persons with PN who sustain a fall-related injury as compared to those who do not.[17] Moreover STV and step width variability on an irregular surface correlate better with a clinical measure of PN severity than does STV on a smooth surface.[7,16] These studies support the concept that measurement of STV on an irregular surface, as compared to that on a smooth surface, offers improved resolution for detecting clinically relevant impairments.

Despite its clinical importance as a gait measure, there is no clear biomechanical explanation for increased STV. As a result the biomechanical necessity, or advantage, of increasing STV on smooth and irregular surfaces has not been clarified. Without an understanding of the mechanism or strategy underlying increased STV the means of reducing it, or even the necessity of trying to do so, remain unclear to clinicians and researchers. Therefore we performed a secondary analysis on data from a prior study of 42 older subjects with neuropathy who walked on smooth and irregular surfaces without intervention, and on an irregular surface with each of three interventions chosen so as to improve frontal plane stability: a cane, ankle orthoses and touch of a vertical surface.[18] In this prior study all three interventions were shown to decrease STV on the irregular surface suggesting that the interventions had a laudatory effect. In the work presented here we theorized that increased STV among neuropathy patients was the result of reduced stability during single stance, a phenomenon we had observed previously in neuropathy patients,[19, 20] which necessitated rapidly placed, shortened recovery steps in order to limit extremes in swing limb lateral foot placement. We further reasoned that the three interventions decreased STV by improving stability during single stance, and therefore allowed increased step length and a reduction in the need for rapid, short recovery steps. Given this reasoning, we tested the following hypotheses: 1) step length (SL) and change in SL (ΔSL = SL irregular surface - SL smooth surface) would demonstrate significant negative correlations with STV and be the best predictors of STV; 2) Change in STV (ΔSTV = STV on the irregular surface - STV on the smooth surface) would demonstrate a significant negative correlation with ΔSL, suggesting that subjects with the greatest decreases in step length on the irregular surface, hence more negative ΔSL, would show the greatest increases in STV; 3) The interventions, which all decreased STV on the irregular surface, would be associated with an increase in SL and a reduction in the strength of the negative associations between STV and SL, and STV and ΔSL; and 4) Subjects would not demonstrate an increased STV as well as an increased step width range (SWR = maximum step width - minimum step width) on the irregular surface, suggesting that increasing STV is a mechanism for preventing large errors in lateral foot placement.

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.[18] 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 50 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.[21]

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

Subject preparation and experimental apparatus

These methods have been used in previous work[7,12,14,16,17,18] and are described in greater detail elsewhere.[14,18] The subjects wore flat-soled athletic shoes supplied by the laboratory and allowed five minutes to accommodate to them. The subjects were placed in a safety harness secured to an overhead track so as to prevent accidental falls on the irregular surface. 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 the smooth surface and then 10 trials on the irregular surface. Subjects were given two minutes rest after the first five trials in each environment and 5 minutes rest after the initial 10 trials. Subjects then repeated the irregular surface trials with the three interventions in a randomized sequence.

To create an irregular surface, a 1.5 × 10 meter piece of industrial carpet was modified by randomly arranging prism-shaped pieces of wood (height = 1.5 centimeter (cm), width = 3.5 cm, length = 6 to 16 cm) beneath the mid 6.5 meter section of the carpet at a density of 26 pieces/meter^2. (Figure 1) Kinematic data were obtained with optoelectronic markers (infrared-emitting diodes) placed 5 cm apart on a malleable aluminum strip (10 cm × 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 (OPTOTRACK)[22] toward which the subject walked within the boundaries of the walkway.

Interventions

The interventions were administered under the supervision of an experienced physical therapist (TD). The cane height was adjusted so that the handle was at the wrist crease when the subject's arm hung in a relaxed fashion at the side.[23] Subjects were taught to use the cane with their non-dominant upper extremity and to place the cane on the ground in synchrony with the contralateral lower extremity. The orthoses (Active Ankle System Inc., Louisville, KY) were placed on each ankle per manufacturer instructions, with the foam-lined shells oriented on the medial and lateral aspects of the ankle and lower leg and held in place with hook and loop straps. The vertical surface used for the wall touch condition was made of dense insulating foam supported on metal struts. Subjects were instructed to use their upper extremity to touch the vertical surface at approximately shoulder height during ambulation. Subjects used the palmar and dorsal surface of their hands, depending on their preferences. A 5-minute period of practice with each of the interventions, in a well-lighted hall with a linoleum floor, was allowed before testing.

Gait data and statistical analysis

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 then 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. Step time was determined by calculating the time elapsed between closure of the right and left metatarsal foot switches. Step width and step length will be defined as the medial-lateral and anterior-posterior distance, respectively, between ankle markers during double support (Figure 1). The variability of step time, step width and step length were defined as the standard deviations of the mean of those measures.

SPSS version 14.0[24] was used for all analyses. Descriptive statistics were generated for clinical and demographic data, and gait parameters for subjects on both surfaces. The standard deviations of step width, step length and step time were used as measures of their variability. All differences between gait parameters on the smooth and irregular walkways were determined by subtracting the smooth surface measurement from the irregular surface measurement. SL and velocity were normalized for height by dividing the SL in centimeters by the subject height in centimeters and the velocity in meters/sec by the height in meters.

The first hypothesis was investigated by determining Pearson correlations between the outcome variables of interest, STV on a smooth and irregular surface, and the following predictor variables: SL, SL variability (SLV), ΔSL, step width (SW), SW variability (SWV) and change in step width (ΔSW). If more than one predictor variable correlated with STV then multiple regression was used to determined the variable(s) with the greatest independent predictive ability. The clinical and demographic data were also explored, secondarily, to ascertain that there were no associations between STV and these variables. If one was identified then it was used in the regression models, along with potential gait variables, to predict STV. To adjust for the number of comparisons performed, a p value of < 0.005 was considered significant, and a p value between 0.005 and 0.010 was considered a trend.

The second hypothesis was investigated using Pearson correlations. The differences in SL with and without the three interventions, associated with the hypothesis 3 were evaluated using a repeated measures analysis of variance with paired t-tests performed post hoc. Hypothesis 3 was also evaluated with Pearson correlations between SL with interventions and ΔSL_{int} (SL on irregular surface with intervention - SL on the smooth surface) and STV on the irregular surface. Hypothesis 4 was investigated by inspecting a scatter plot of STV on the irregular surface and step width range. For hypotheses 2 and 3, a p value of < 0.05 was considered significant and a value between 0.05 and 0.10 considered a trend.

Lastly, when linear correlations were not identified, scatter plots of the data were inspected and non-linear analyses performed as needed. No significant, or near significant, non-linear relationships were identified.

RESULTS

Clinical/demographic variables

Twenty of the 42 subjects were women. The means and standard deviations of the gait measures of interest are shown in Table 1. The mean (standard deviation) age, body mass index and MDNS scores were 65.9 (10.4) years, 32.1 (6.9) and 17.6 (5.5), respectively. There was a significant positive correlation between STV on the flat and irregular surfaces (Pearson correlation = 0.446; $p = 0.003$). STV on the flat surface showed a significant positive correlation with age and a negative association with body mass index. (Table 2) STV on the irregular surface did not show a significant correlation with any of the demographic or clinical variables.

Hypothesis 1: The relationship between STV, SL and ΔSL

Consistent with the hypothesis, STV on the smooth and irregular surfaces showed trends toward significant negative relationships with SL on the irregular surface and significant negative relationships with ΔSL (Table 3); however, SL on the smooth surface did not correlate with STV on either surface. The relationships between ΔSL and STV on the smooth and irregular surfaces were much stronger than the relationships between SL and STV on smooth and irregular surfaces, with R^2 values of the former approximately double those of the latter. (Table 3) SLV and STV showed no relationship on either surface. A significant positive correlation between ΔSW and STV on the irregular surface was also noted. (Table 4)

Using regression analysis for STV on the smooth surface as the outcome of interest, body mass index ($p = 0.014$) and ΔSL ($p < 0.001$) were the only significant predictors, and yielded an adjusted R^2 of 0.389. When using STV on the irregular surface as the outcome of interest, only ΔSL was a significant predictor of STV; ΔSW and SL became insignificant whenever ΔSL was added to the model. The best model for the prediction of STV on the irregular surface included only ΔSL and yielded an adjusted $R^2 = 0.417$. Therefore ΔSL was the strongest predictor of STV on both the smooth and irregular surfaces.

Hypothesis 2: The relationship between ΔST and ΔSL

Consistent with the hypothesis, ΔSTV and ΔSL demonstrated a significant negative correlation ($R = -0.341$; $p = 0.029$) suggesting that the subjects with the greatest decreases in step length on the irregular surface showed the greatest increases in STV.

Hypothesis 3: The relationship between STV, SL and ΔSL with interventions

Consistent with the hypothesis, SL (given as a fraction of body height) on the irregular surface increased with each of the three interventions (0.293 ± 0.043, 0.276 ± 0.045 and 0.282 ± 0.041 for cane, orthoses and wall, respectively) as compared to SL on the irregular surface without interventions (0.269 ± 0.044; $p < 0.001$ for all three comparisons). Also consistent with hypothesis SL on the irregular surface and ΔSL_{int} were not as strongly associated with STV on the irregular surface when subjects used the interventions (Table 5) as compared to the baseline condition without intervention (Table 3). When using the interventions, R^2 values for the relationships between SL and STV on the irregular surface were approximately one half that without intervention. Similarly, when using the interventions R^2 values for the relationships between changes in ΔSL_{int} and STV on the irregular surface were less than half of that without intervention. When SL and ΔSL_{int} were entered into linear regression with STV with interventions as the outcomes of interest, the resultant adjusted R^2 values of 0.168, 0.173 and 0.128 (for cane, orthoses and wall touch, respectively), were also less than half the adjusted R^2 of 0.401 obtained with the same two variables when interventions were not used.

Hypothesis 4: The relationship between STV and SWR

When STV is plotted against SWR (Figure 2) it can be seen that none of the subjects demonstrated an increased STV as well as an increased step width range.

DISCUSSION

Hypothesis 1: The relationship between STV, SL and ΔSL

The main finding of this work is that, among older persons with neuropathy, a strong inverse relationship exists between STV on smooth and irregular surfaces and ΔSL when subjects are challenged with an irregular surface. In other words, the greater the magnitude of change in SL to accommodate to the irregular surface the greater their STV. Although SL on the irregular surface also correlated inversely with STV on smooth and irregular surfaces, multivariate analysis showed that ΔSL was the best predictor of STV on both surfaces. Interestingly, neither SL on a smooth surface nor SL variability on either surface showed any relationship with STV on either surface.

One way to interpret these relationships is to consider an older person with neuropathy walking on an irregular surface. During ambulation on such a surface the stance foot lands randomly on non-horizontal surfaces which in turn cause random changes in the ground reaction force location under the foot. The challenge to the neuropathy patient walking over such a surface is to counteract the changes in ground reaction force so as to control the center of mass for a sufficient amount of time that swing limb trajectory and foot placement are minimally affected. Recent work has demonstrated that rapid force generation by the stance limb at the ankle is required for successful recovery from such perturbations.[25,26] If such a counteraction is not possible, as is likely often the case for subjects with PN due to delayed recognition of ankle rotations[27] and impairments in ankle rate of torque generation,[28,29] then the trajectory of the swing limb will not be controlled possibly leading to an improperly placed foot relative with resultant loss of balance. An alternative strategy, which has been identified during stance limb perturbation protocols in healthy young and older subjects, is to rapidly unload the perturbed unstable stance limb by shortening the subsequent step time and step length.[30,31] Moreover during dual stance lateral translation studies subjects with a hypothermia-induced reduction in plantar sensation, analogous to the effects of PN, were four times as likely to use multiple small steps to recover balance as compared to their baseline. This was thought to be due to instability during single limb support.[32] Such strategies employed on an irregular surface would, in aggregate, lead to reduced SL as well as increased STV resulting in an inverse relationship between these two gait measures. In contrast, when on a smooth surface the neuropathy subjects presumably have sufficient stability during single stance that shortened, rapidly executed "rescue" steps are less frequently necessary leading to an absence of relationship between STV and SL on that surface. The absence of a relationship between SLV and STV on the irregular surface may be related to the fact that subjects, when stressed by poor balance, have a stereotypical "rescue" step that is relatively consistent in length (short) that takes different amount of time to execute. If so, then SLV would minimally increase while STV would substantially increase. However, in the absence of confirmatory kinematic data this is supposition.

Other work supports our findings. Menz et al. studied younger and healthy older subjects walking on smooth and irregular surfaces, and found that the older subjects decreased speed and step length while increasing STV as compared to the younger subjects, but that the two groups did not differ with regard to accelerations of the head and pelvis.[1] It was concluded that the gait changes on the irregular surface allowed the older subjects to compensate in some way for their lower extremity physiologic deficits. Another study by the same group found that, in a group of older subjects walking on an irregular surface, decreased step length was associated with fear of falling, lower extremity sensorimotor function and decreased head stability.[33] Because of the last finding it was concluded that shortening step length in response to a challenging environment may be maladaptive. However if the goal is to minimize aberrant steps in the frontal plane, rather than stabilize the head, then the shortening of step length, at least intermittently, may be adaptive.

Although the relationship between ΔSL and STV on the irregular surface is intuitive, it is more surprising that ΔSL was the best predictor of STV on the smooth surface. Given the relationships between increased STV, various pathologies and fall risk, it is likely that increased STV on a smooth surface is a marker for instability during single stance. In that light it is not surprising that subjects with increased STV on smooth surfaces would need to intermittently shorten their stride to adapt safely to an irregular surface, and thus giving the observed relationship between ΔSL and STV on a smooth surface.

Hypothesis 2: The relationship between ΔST and ΔSL

Other findings also support the concept that shortening SL on the irregular surface leads to an increase in STV. The negative correlation between ΔSTV and ΔSL suggests that the subjects with the greatest decreases in step length on the irregular surface showed the greatest increases in STV.

Hypothesis 3: The relationship between STV, SL and ΔSL with interventions

When the subjects used the interventions on the irregular surface their step lengths increased, as compared to trials when they walked on the irregular surface without the interventions, the strengths of the relationships between ΔSL_{int} and STV on the irregular surface weakened markedly. It is interesting to note that the interventions all provided lateral support, suggesting that greater frontal plane stability allowed step length to increase and STV to decrease. Therefore the intervention data also support the concept that an increased STV may be, in part, an adaptation to impaired dynamic lateral balance in patients with neuropathy.

Hypothesis 4: The relationship between STV and SWR

Did increasing STV on the irregular surface lead to a reduction in improperly placed swing limbs in the frontal plane? It is interesting to observe SW range (step width maximum - step width minimum for each subject), a measure of the greatest deviation in lateral foot placement in the frontal plane, plotted with STV (Figure 2). Inspection of the data shows that none of the subjects demonstrated an increased STV as well as an increased SW range on the irregular surface, suggesting the possibility that subjects increased STV on an irregular surface to the extent necessary to maintain SW range within some level of tolerance. Given the critical role of lateral foot placement in maintaining frontal plane balance,[34,35] and given the injury potential of lateral falls,[36] the data are consistent with the idea that increasing STV among older subjects with PN on an irregular surface is a mechanism to maintain control in the frontal plane. Similar findings were noted by Barak et al.[37] who found that a group of older adults with positive fall histories showed decreased stride length and center of mass sway on a treadmill as compared to older adults without a history of falls. The authors suggested that the fallers decreased stride length to minimize lateral instability, noting that the greatest lateral momentum is generated at push-off.

Although neuropathy is a common diagnosis in many countries, for example affecting between 15 and 20% of older persons in the United States,[38,39] an important limitation to this study is that the findings can only be applied to older persons with neuropathy. However, the findings can likely be applied to older neuropathy patients with some confidence given the sample of 42 subjects is relatively large for a highly quantified study such as this one. Another limitation is that the subjects all walked on the smooth surface prior to the irregular surface. However subjects likely became more comfortable in the laboratory with repeated trials so that gait differences between the smooth and irregular surfaces would be, if biased by an order effect, minimized. Given the usual close relationship between velocity and SL there is also concern that a decrease in velocity on the irregular surface, rather than a decrease in SL, could be the cause of increased STV as has been noted by others.[40] To evaluate this change in velocity was evaluated post-hoc and showed weaker correlations with STV than did change in SL. Moreover when change in velocity was entered in place of change in SL into multivariate models used to predict STV, the corresponding R^2 values decreased. Therefore it appears that it is a decrease in SL on an irregular surface, rather than decrease in walking speed, that underlies increased STV. A reduced SL has also been associated with fear of falling, and because this variable was not measured, we cannot comment on its influence. Finally, although ΔSL explained approximately 40% of the variance in STV on smooth and irregular surfaces, more than half of the variance in STV remains unexplained. Further research is therefore necessary in order to more fully understand this increasingly important gait measure.

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Figure 1.

Schematic diagram of the irregular surface, marker placement and definitions of step width and length

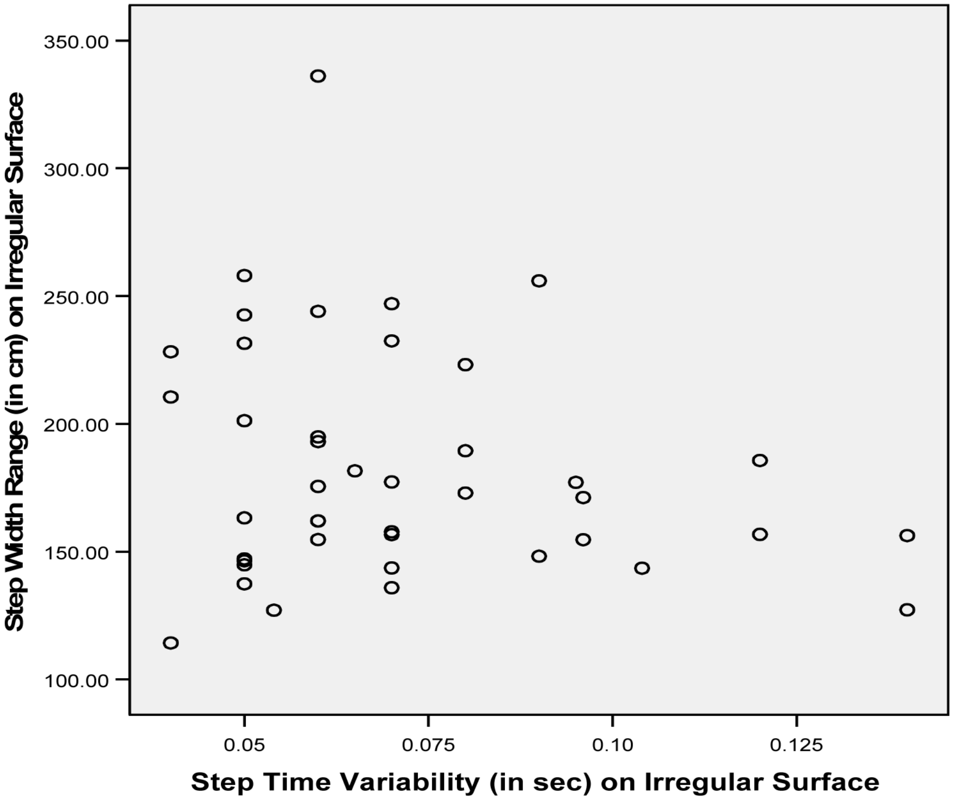

Figure 2.
Step time variability plotted against step width range (the difference between step width maximum and step width minimum). Note that subjects did not simultaneously demonstrate increased step width range and step time variability.

Table 1

Means and Standard Deviations of Gait Measures of Interest on the Smooth and Irregular Surfaces

Surface	Mean Step Width (cm)	Step Width Variability (cm)	Step Width Range (cm)	Mean Step Length (cm)	Step Length Variability (cm)	Mean Step Time (sec)	Step Time Variability (sec)
Smooth	180.5 ± 32.4	34.4 ± 8.4	159.7 ± 39.6	499.9 ± 75.3	32.9 ± 13.3	0.63 ± 0.05	0.035 ± 0.015
Irregular	197.1 ± 40.8	40.4 ± 8.9	182.6 ± 45.6	563.4 ± 93.6	39.0 ± 11.0	0.66 ± 0.07	0.071 ± 0.025

Table 2

Correlations between clinical variables and STV on both surfaces

	Age **Pearson Corr./*P* value**	**Body Mass Index** **Pearson Corr./*P* value**	**MDNS**[*] **Pearson Corr./*P* value**
STV smooth	0.314/0.043	-0.413/0.007	0.086/0.590
STV irregular	0.084/0.596	-0.110/0.487	-0.186/0.239

[*] Michigan Diabetes Neuropathy Score

Table 3

Correlations between step length variables and STV on the smooth and irregular surfaces

	Step Length (SL) **Pearson Corr./*P* value** R^2		**Step Length Variability (SLV)** **Pearson Corr./*P* value** R^2		**Change in Step Length (ΔSL)** **Pearson Corr./*P* value** R^2
	Smooth	**Irregular**	**Smooth**	**Irregular**	**Smooth - Irregular**
STV smooth	-0.173/0.274 $R^2 = 0.029$	-0.399/0.009* $R^2 = 0.159$	0.023/0.886 $R^2 < 0.01$	0.174/0.272 $R^2 = 0.03$	-0.565/<0.001† $R^2 = 0.31$
STV irregular	-0.080/0.613 $R^2 = 0.006$	-0.433/0.005* $R^2 = 0.187$	-0.090/0.570 $R^2 < 0.01$	0.080/0.615 $R^2 < 0.01$	-0.656/<0.001† $R^2 = 0.430$

† Significant relationship

* Trend

Table 4

Correlations between step width variables and STV on the smooth and irregular surfaces

	Step Width (SW) Pearson Corr./*P* value R^2		**Step Width Variability (SWV) Pearson Corr./*P* value R^2**		**Change in Step Width (ΔSW) Pearson Corr./*P* value R^2**
	Smooth	**Irregular**	**Smooth**	**Irregular**	**Smooth - Irregular**
STV smooth	0.097/0.541 $R^2 < 0.01$	0.291/0.062 $R^2 = 0.08$	0.026/0.873 $R^2 < 0.01$	-0.077/0.627 $R^2 < 0.01$	0.388/0.011 0.15
STV irregular	-0.056/0.725 $R^2 < 0.01$	0.247/0.115 $R^2 = 0.06$	-0.039/0.804 $R^2 < 0.01$	-0.162/0.305 $R^2 = 0.093$	0.529/< 0.001[†] 0.280

[†] Significant relationship

Table 5

Correlations between STV and SL on the irregular surface, and between STV and ΔSL, when using interventions known to decrease STV

	Step Length Irregular Pearson Corr/*P* value R^2			**Delta Step Length Pearson Corr/*P* value R^2**		
	Cane	**Orthoses**	**Vertical Surface**	**Cane**	**Orthoses**	**Vertical Surface**
Step Time Variability, Irregular	- 0.361/0.019 $R^2 = 0.13$	- 0.313/0.047 $R^2 = 0.098$	- 0.346/0.025 $R^2 = 0.12$	- 0.441/0.004 $R^2 = 0.19$	- 0.463/0.002 $R^2 = 0.21$	- 0.373/0.015 $R^2 = 0.14$