

Abstract

Background: Gait speed is used to predict health status and disability. Gait speed and its underlying spatiotemporal measures have been studied on level clinic surfaces and outdoor firm surfaces. However, the change in gait speed that occurs from a smooth, firm clinic setting to various outdoor terrains an individual may encounter in the community has not been studied.

Methods: Average gait speed, step length, and cadence were determined for 49 participants on the indoor 10 Meter Walk Test and six outdoor terrains: large pavers, sand, up and downhill gravel, mulch, and small pavers. Outcome measures were compared between conditions using a one-way repeated measures ANOVA, repeated for terrain. To determine the relationship between gait speed changes and both cadence and step length changes across conditions we used step-wise, multiple linear regression.

Results: There was a significant main effect across all terrains for gait speed ($p < 0.001$; $\eta_p^2 = 0.644$), cadence ($p < 0.001$; $\eta_p^2 = 0.323$), and step length ($p < 0.001$; $\eta_p^2 = 0.597$). Gait speed was significantly slower on sand, mulch, and going up and downhill on gravel (all $p < 0.023$). Cadence and step length were significantly reduced on sand and going up and downhill on gravel (all $p < 0.006$ and $p < 0.017$, respectively). A combination of step length and cadence changes accounted for >94% of the variance in gait speed change from the 10MWT to sand speed ($p < 0.001$, $R^2 = 0.938$), mulch speed ($p < 0.001$, $R^2 = 0.962$), downhill gravel speed ($p < 0.001$, $R^2 = 0.937$), and uphill gravel speed ($p < 0.001$, $R^2 = 0.938$).

Conclusion: Indoor gait speed during a 10MWT is not representative of the speed individuals will use when walking on various outdoor terrains. Reduction in both step length and cadence results in this reduction in gait speed. Gait training should take place on the terrains individuals are expected to encounter upon reentering the community.

Introduction

A primary role of physical therapists is to restore independent mobility in the community for patients who have deficits with balance and mobility impairments. Improving gait is often listed as a primary goal of both patients¹ and therapists, indicating its importance for physical functioning and quality of life. As such it is critical that therapists are able to objectively measure gait outcomes to ascertain their importance for community functioning. In particular, physical therapists frequently use the measure of gait speed in clinical settings, as it has previously been found to be a reliable predictor of health status and disability.²⁻⁴ In addition, decreased gait speed can lead to reduced participation in community activities as well as increased safety concerns, particularly in urban areas.^{5,6}

A number of injuries and disabilities can cause mobility deficits leading to decreased gait speed, such as hip fracture, stroke, and spinal cord injury.^{4,7-9} Normative values have been established for gait speed using the 10 meter walk test in healthy adults to use as a comparison for people with mobility deficits.¹⁰ Additionally, cut off scores have been defined that are used to classify a person's ambulation status, with lower speeds predictive of household and limited

community ambulation and higher speeds predictive of unlimited community ambulation ability.^{3,11}

Importantly, however, these norms and cut off scores were derived from measures taken in clinical settings that are well lit, indoors, and over a clear, flat surface. Instead, walking in the 'real world' is not simulated in this environment and is therefore not indicative of how individuals with mobility deficits might be actually walking in the community. In particular, people seldom walk on smooth, well-lit floors once they venture out of their homes. Instead, we must contend with various slopes and surface textures. These textures include different surface stiffnesses and as such have different requirements for balance and dynamic stability.¹² Because patients seeking physical therapy for mobility deficits often present with balance deficits, it is likely that a transition to such terrains would require adaptations in gait speed to compensate.

Gait speed is affected by changes in spatiotemporal measures, which include step length and cadence.^{13,14} Typically, gait speed is increased by increasing step length and also increasing cadence,^{13,14} and step length and/or cadence is understood to change with age,¹⁴ on varying surface stiffnesses,¹² and with various mobility impairments, such as Parkinson's disease.¹⁵ For example, decreases in gait speed of older adults is mainly attributed to a reduction in step length, while cadence remains largely similar with only minor reduction.^{14,16} Walking on up- or down-sloped surfaces, also has an effect on step length and cadence. When walking downhill, step length tends to decrease more as the angle of the slope is increased, while walking uphill causes a reduction in step length, cadence, and gait speed that is also greater as the angle of the slope increases.¹⁷

There are many studies that define the characteristics of gait, gait speed, and its underlying spatiotemporal measures on level clinic surfaces or outdoor firm surfaces, however, few studies have addressed ambulation over varying terrains and, to our knowledge, there are no studies that compare indoor clinic gait speed to outdoor, community settings with typical community terrain obstacles such as gravel, mulch, slopes, etc. for people with mobility deficits.^{5,18-20} It is therefore important to understand how our measures of gait obtained on a smooth, firm standard floor translate to other typically encountered terrains in the community.

The purpose of this project was to quantify the change in gait speed that occurs from a smooth, firm clinic setting to various outdoor terrains that a patient may encounter in the community such as pavers, sand, upward and downward sloping gravel, and mulch. Our hypothesis is that the participants' gait speed, obtained via the 10 Meter Walk Test in the clinic, will be reduced when traversing the various outdoor terrains. If this is the case, we aim to ascertain which spatiotemporal mechanism, cadence and/or step length, contributes to this change in gait speed so that instruction can be tailored in a manner that best supports restoration of gait speed and safe re-entry into the community.

Methods

Participants

We recruited 49 participants with mobility deficits due to musculoskeletal or neurological deficits. All participants were recruited at the site of the data collection via identification from their physical therapist. To be included in the study, the participants were required to ambulate with contact guard assist (CGA) or less, with or without an assistive device

and/or orthotic, and were restricted to the age of 18 or older. Participants with comorbidities, such as partial blindness or dementia, were not excluded; two participants who spoke Spanish participated with the assistance of an interpreter. All participants signed an informed consent form approved by the IRB at the University of North Carolina at Chapel Hill.

Data Collection

Data collection occurred at the UNC Center for Rehabilitative Care in the therapy gym, and on their outdoor 'Challenge course'. Participants were recorded with a standard video camera completing the 10 Meter Walk Test (10MWT) indoors and covering all parts of the Challenge course in the same order. One investigator reviewed consent paperwork with each participant, provided instructions on the 10MWT and outdoor course, and walked behind all participants to provide hand signals indicating when they were in line with the course markers. The second investigator collected demographic, subjective, and objective information, and captured video of all participants during indoor and outdoor testing. Participants who ambulated with contact guard assistance were guarded by their physical therapist, while participants who ambulated independently were usually unaccompanied.

The 10MWT was conducted indoors on a linoleum floor, in a well-lit corridor free of obstacles. The start and finish markers were on the floor in the form of blue tape, however participants were instructed to disregard those marks. Participants were allowed to use an assistive device, prosthetic, and/or orthotic, as needed. Prior to beginning the test, participants were instructed to stand about 2 meters behind the first marker to provide an acceleration zone. The instructions given were, "When I say 'start,' I would like for you to walk all the way to

the opposite wall at a pace that is comfortable and safe for you.” The finish marker was several feet away from the opposite wall, so once the participant had passed over the marker they could safely decelerate. In most cases the 10MWT was conducted prior to the outdoor course, with a few exceptions due to time constraints surrounding the participant’s appointment time.

The participants were asked to make one clockwise and one counter-clockwise loop around the outdoor course. In the clockwise direction, the course consists of five varied terrains: large cement pavers, sand, downhill sloping gravel, mulch, and small cement pavers [see Table 1 for path distances]. Distances of each terrain were measured with a measuring wheel and flags were posted as markers to be visible on the videos. In the counter-clockwise direction, participants navigated the same terrains in reverse, resulting in the gravel terrain being sloped upwards. Participants were instructed to use the same assistive device, prosthetic, and/or orthotic that was used on the indoor 10MWT. The same verbal instructions were given regarding ambulating on the outdoor course, “I would like for you to walk around the course at a pace that is comfortable and safe for you.” Verbal and visual cueing was used while on the course to direct participants to the next terrain. Between the two loops, participants were allowed to take a standing, propped, or seated rest for up to 5 minutes, if requested.

Table 1

Terrain	Distance (meters)
10MWT (indoors)	10
Large Pavers	21.9
Sand	4.2
Gravel (up/downhill)	11.9
Mulch	6
Small Pavers	5.8

Data Processing

Video clips of participants were downloaded to a standard PC and processed by the two investigators and a lab assistant. Data processing started by counting steps and recording start and finish times for each terrain, to the nearest tenth of a second. For every terrain (including the indoor 10MWT) the time began and ended when the participant's torso was in line with the marker (or flag). When counting the number of steps, the first step where the foot was more than halfway past the marker was counted (heel or completely past). Steps were counted until the last step prior to the final marker. If the last step was in line with the marker, it was only counted if the foot was less than halfway past (toes/forefoot) the marker. If the participant stopped on the course, the time was not stopped and step counting resumed when they began to ambulate again. When fully visible in the video, the markers laid out indoors and on the outdoor course were used to establish start and finish points; however, when not easily viewable the investigator's hand signal was used as a guide. The time each participant required to navigate each terrain was calculated and used along with the distance and the number of steps on the terrain to calculate the participant's average gait speed (distance/time), cadence (steps/time), and step length (distance/steps).

Data Analysis

Data analysis was performed in SPSS v24. Each of the outcome measures (gait speed, cadence, step length) were compared between conditions using a one-way repeated measures ANOVA, repeated for terrain. In the presence of significant main effects, we used paired samples T-tests as post-hoc tests. Multiple comparisons were accounted for using Bonferroni

corrections. To determine the relationship between gait speed changes and both cadence and step length changes across conditions we used step-wise, multiple linear regression. P values less than 0.05 were considered significant.

Results

There were 50 interested participants who signed the informed consent form and completed the 10MWT, however, one participant was excluded from data analysis because she was unable to complete any outdoor terrain segments due to extreme fatigue. Of the 49 people included in the data analysis, there were 22 males and the average age of all participants was 65.2 ± 15.8 years old (range from 23.1 to 86.4 years old). Participant diagnoses included 11 with Parkinson's disease, 8 recovering from stroke, 19 with musculoskeletal complaints (arthritis, amputation, pain, etc.), 4 who suffered trauma (traumatic brain injury, spinal cord injury, pain due to motor vehicle crash injury), and 7 other conditions (spina bifida, cancer related pain, falls prevention, multiple sclerosis, shortness of breath with weakness). There were eight participants who used a cane (one of those had a knee brace), two participants utilized a Bioness, two wore ankle braces, one wore an ankle foot orthotic, one used a trans-femoral prosthetic, one used bilateral trans-tibial prosthetics, and one participant had a shoe lift. Twenty-three participants reported a history of falls. Of those reporting falls, the number reported ranged from 1 to 12 within the past year, with an average number of 2.4 falls for each faller.

We observed a significant main effect for gait speed across the different walking terrains ($p < 0.001$; $\eta_p^2 = 0.644$). Specifically, we noted that subjects walked significantly slower on sand,

mulch, and going up and downhill on gravel (all $p < 0.023$). Both large and small pavers did not produce a significant change in speed. [see Figure 1]

We also observed a significant main effect for cadence ($p < 0.001$; $\eta_p^2 = 0.323$), as well as step length ($p < 0.001$; $\eta_p^2 = 0.597$), across the different walking terrains. We noted that the cadence and step length of the subjects was significantly reduced on sand and going up and downhill on gravel (all $p < 0.006$ and $p < 0.017$, respectively). Neither mulch nor large or small pavers produced a significant change in cadence or step length. [see Figure 2 and 3]

The change in gait speed was significantly related to the combination of change in step length and change in cadence going from the 10MWT condition to the sand, mulch, and up and downhill gravel conditions. Specifically, we observed that the combination of step length and cadence changes accounted for 94% of the variance in gait speed change from the 10MWT speed to the sand speed ($p < 0.001$, $R^2 = 0.938$), 96% of the variance in gait speed change from the 10MWT speed to the mulch speed ($p < 0.001$, $R^2 = 0.962$), 94% of the variance in gait speed change from the 10MWT speed to the downhill gravel speed ($p < 0.001$, $R^2 = 0.937$), and 94% of the variance in gait speed change from the 10MWT speed to the uphill gravel speed ($p < 0.001$, $R^2 = 0.938$).

Figure 1

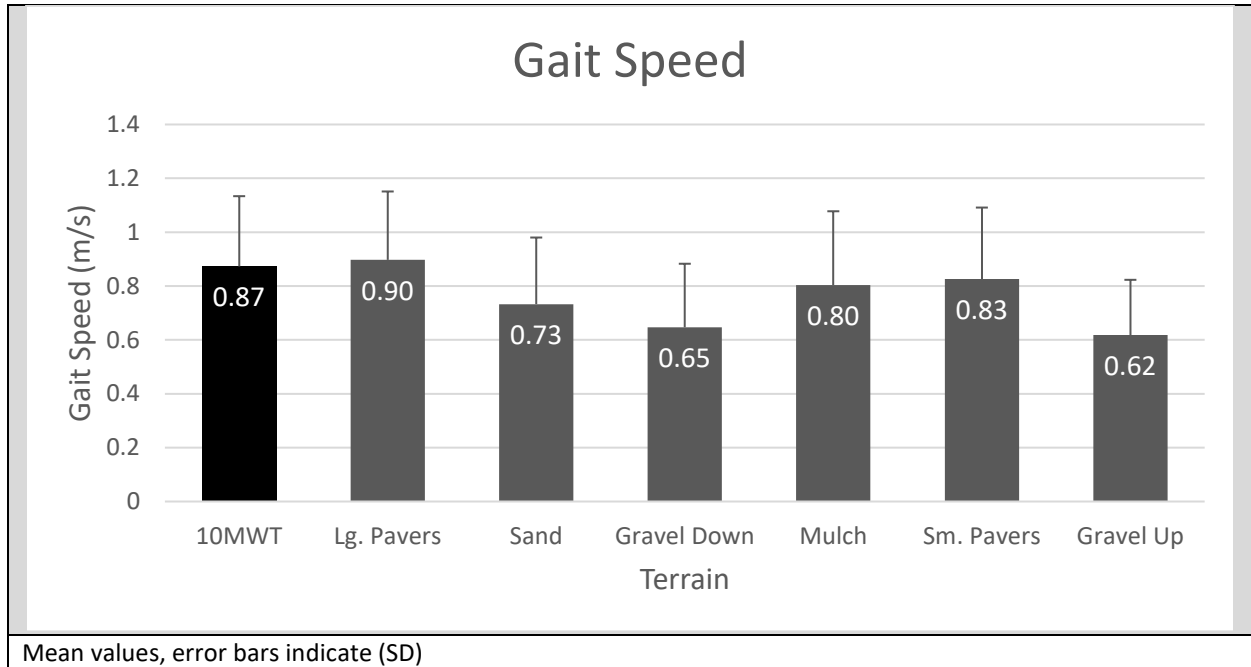


Figure 2

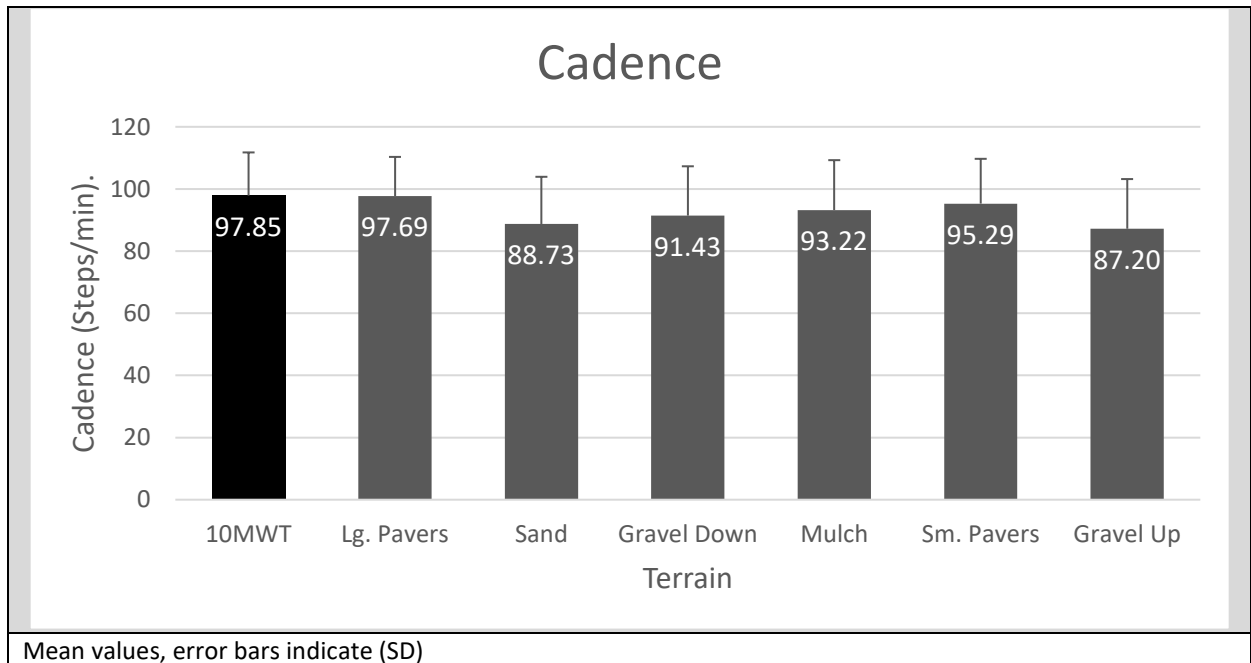
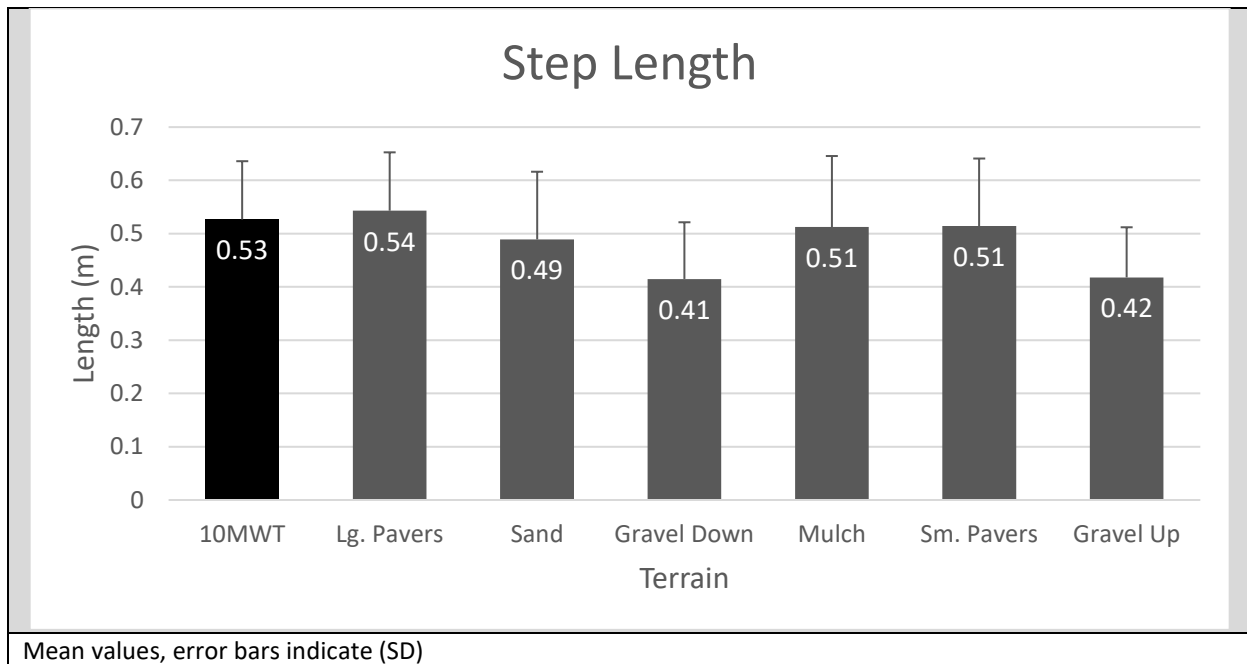


Figure 3



Discussion

Our hypothesis that the participants' gait speed, obtained via the 10MWT in the clinic, would be reduced when traversing the various outdoor terrains was partially supported by the data. There was a reduction in gait speed when walking on sand, mulch, and walking up and downhill on gravel, although there was no change in gait speed walking on large or small pavers. With regard to the spatiotemporal measures of step length and cadence, both were reduced when walking on sand and up and downhill on gravel. It was determined that both the reduction in step length and reduction in cadence were concurrently responsible for the reduction of speed on the aforementioned terrains. This has important implications for individuals who wish to resume walking on outdoor terrains.

Our results have the potential to influence the structure of physical therapy treatments. Previous literature has suggested that patients with mobility deficits, such as stroke, are more likely to achieve the step quantity needed for limited community ambulation if their gait speed in the clinic is greater than 0.49 m/s, and are more likely to be able to achieve the step quantity needed for unlimited community ambulation if their gait speed is at least 0.93 m/s.¹¹ The mean gait speed of our participants was 0.87 m/s on the 10MWT. Based on these values, the majority of our participants are most likely considered limited community ambulators, however the mean gait speeds on sand, mulch, uphill gravel, and downhill gravel were 0.73 m/s, 0.80 m/s, 0.62 m/s, and 0.65 m/s, respectively. Although they may be capable of some aspects of community ambulation, this reduction in speed may indicate that the participants are not ready for the increased demand those terrains require. Additionally, as average comfortable gait speed for healthy adults in the age range of our participants' is between 1.27 and 1.46 m/s,¹⁰ this difference is a noteworthy indication of their ability to keep up with their peers in everyday life. It is clear that using these guidelines for discharge planning are not sufficient, and to truly prepare our patients for community ambulation and participation we should be training and testing them on the types of terrains they will be expected to traverse following discharge.

Navigating compliant terrains, like those in our study, requires greater amounts of dynamic stability.¹² Importantly, gait differed from the indoor 10MWT only when participants walked on unstable surfaces (i.e. sand, mulch, gravel hills), but not on the stable outdoor surfaces (i.e. pavers). Under unimpaired conditions, step length will increase on compliant unstable surfaces to help increase the base of support.¹² Therefore, it is important not only to gait train our patients on these surfaces, but also to focus on the cause of the reduction in gait

speed – reduced step length and reduced cadence. This information should be used when informing instructional cues during gait training, as well as incorporating usual exercises and activities into therapy for increasing lower extremity strength and dynamic balance.

There were some limitations to our study. First, we did not formally track which participants had been on the outdoor Challenge course prior to our observations. It is possible that those that had been on the course previously would not have shown as much of a difference in walking speed outdoors due to their training. If anything, based on our results, we believe that if we had limited our study only to participants who had not yet been on the course, the difference in mean gait speeds might have been larger. Secondly, it is possible that the pace of the therapist and/or investigator could have unintentionally influenced the participant's speed on the course. However, given that some participants required CGA or close guarding for safety, this seems to be an unavoidable limitation. Finally, we did not have a control group of unimpaired participants to compare against our results. Nevertheless, in comparing the participants' mean gait speed on the various terrains against their own indoor 10MWT mean gait speed, we believe that the information we gained still has clinical significance to the practice of physical therapy.

One strength of our study is the variety of patient populations included in the study. This allows our results to be generalizable to the treatment of a broader range of mobility deficits. In addition, the use of a video recorder and verification (i.e. flags, landmarks, and hand signals) of start and finish lines for each outdoor terrain path contribute to the accuracy and precision of the data collected. These procedures allowed for less possibility of human error in

counting steps and recording times as well as the ability of the video clip to be reviewed by more than one investigator for clarification.

Future research may include an assessment of training on various types of outdoor terrains to determine influence of such training on gait over uneven terrains. Such information would provide important information about the best method(s) for more complete rehabilitation of patients with mobility deficits.

Conclusion

The gait speed of patients observed indoors during a 10MWT is not representative of the speed they will use when walking on various outdoor terrains. Their reduction in gait speed is a result of a reduction in both step length and cadence. Physical therapists should be training patients on the terrains they expect them to encounter once they reenter the community along with other interventions targeting dynamic balance and strength.

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