Original Article

Temporo-spatial gait adaptations while walking on different surfaces in Latino-Hispanic adults with controlled type II diabetes

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ABSTRACT

Those with Type 2 Diabetes with and without peripheral neuropathy (PN) display evident gait deficiencies, and kinematic alterations while stepping on various surfaces. Purpose: To verify if such modifications would emerge performing diverse tasks in the regulated stages of diabetes such as controlled type 2 diabetics without PN. Methods: We recruited and allocated 30 adult participants in two groups, 15 controlled diabetics (cDMII) and 15 controls (CoG). Gait temporospatial criteria were measured during even walkway and described concerning a ramp/slope surface, and a stair-step. Results: A Repeated measure ANOVA was employed to compare even surface gait parameters with slope and stair (ascending and descending) surfaces within each group. Our results highlight that cDMII shows distinct and initial traces of impaired gait parameters, notably on single-limb support time reduction with a double-limb time increment during ramp compared to even surface. Conclusion: Our conclusions suggest even at the early stages of diabetes, when glucose levels are regulated, adjustment while shifting and adapting to different, more challenging surfaces appear, notably in dynamic balance variables. Therefore, making this prompt detection of variations is clinically valuable for providing treatment interventions to diminish the risk of falls and trauma in those who have diabetes.

Keywords: Controlled diabetes; Gait modifications; Temporospatial parameters.

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INTRODUCTION

Type 2 diabetes mellitus (DMII) imposes negative impacts on the nervous and circulatory systems, with the most common complication being peripheral neuropathy (PN), a condition in which peripheral nerves degenerate (Richardson et al., 2004). Frequently, this degeneration in the lower limbs leads to reduced range of motion at the ankle joint, slower walking velocity, shorter strides, and shorter step lengths. While these changes contribute to gait deficiencies, they also contribute to impairments in maintaining balance (Mueller et al., 1994). The balance impairments caused by DMII increase the risk of falls, even before PN and its associated complications manifest (Dingwell et al., 2000; Petrofsky et al., 2005). Individuals are often unaware that they have DMII until PN or other complications related to the disease (e.g., ulcers, frequent falls) emerge, making the detection of PN symptoms at the earliest stage essential for both health and safety of those afflicted with DMII.

The effect that DMII has on gait is known for individuals with uncontrolled blood glucose levels. Aside from our studies which have evaluated balance deviations, along with ascending and descending a ramp at an imposed speed, current literature is limited in published studies that investigate the gait of diabetic patients who are identified as having their glucose levels under control and are without known peripheral neuropathy (cDMII) (Rosario et al., 2020; Rosario et al., 2018).

Our study of cDMII participants ascending and descending a ramp did not yield any gait modifications distinguished to the control subjects (Rosario et al., 2018). However, those with cDMII exhibited a distinct standing posture instability while performing different challenging tasks, that increased in anterior-posterior sway when the vestibular (head movements) and somatosensory (standing on foam) systems were challenged, simultaneously (Rosario et al., 2020). The above alludes to the possibility that the use of more challenging, irregular, and elevated surfaces may reveal additional deficiencies compared to flat and even surfaces (Allet et al., 2009). Uneven surfaces, such as a ramp and stairs, are an important surface design to investigate because, for any population, falls on these surfaces are a major cause of injury and death, especially during stair descent (Cohen, 2000). Prior studies showed that the risk of falls by people with diabetes on stairs, or any other surface is further increased compared to healthy individuals (Agrawal et al., 2010; Maurer et al., 2005; Schwartz et al., 2002). This study intended to determine if a ramp or stair surface would further divulge these deficiencies and modifications among those with controlled diabetes. We investigated the temporospatial characteristics of gait during the ascent and descent of a ramp, and a single stair step differed to the less challenging 3-meter even-surfaced walkway.

The current study aims to identify gait modifications when shifting surfaces from an even-surfaced walkway to a more demanding surface, such as ramps and stairs, in Hispanic-Latinos with controlled diabetes. In comparison to healthy individuals, we strive to differentiate the gait of cDMII participants while ascending and descending both stairs and a ramp, in contrast to walking on an even surface.

METHODS

The University Institutional Review Board approved the study protocol. Each subject was informed of the objective of this research study and their role in this investigation through verbal communication, as well as in written form, before signing the informed consent form.

Subjects

This study recruited fifteen adults (eight males and seven females, age = 57.7 ± 5.12 years, weight = 176.6 ± 75, height 65.8 ± 4.3 inches) with controlled (HbA1c ≤ 7.5) type two diabetes and no history of peripheral neuropathy (cDMII) to the cDMII group. For the control group (CoG), we recruited fifteen healthy adults (seven males and eight females, age = 54.4 ± 6.28 years, height 64.5 ± 3.9 inches, weight = 162.2 ± 8.6).

Participation criteria

cDMII group

The inclusion criteria for the cDMII group participants consisted of (1) having a Type II diabetes diagnosis, and (2) being between the ages of 40 and 64.

The exclusion criteria for the cDMII group were (1) uncontrolled glucose levels (i.e., HbA1c > 7.5%), (2) the inability to walk, (3) a severe balance impairment (≥ two falls within the last six months), (4) any history of surgery on the lower limb or back, (5), lower limb neurovascular problems, such as ulcers, (6) pregnancy, and (7) other types of diabetes, such as Type I.

Control group

The inclusion criteria for participants in the CoG consisted of (1) having reasonable health (no metabolic syndrome), and (2) being 40-64 years of age.

The exclusion criteria for the CoG were (1) having a diagnosis of any type of diabetes, (2) a severe balance impairment, (3) any lower limb or back surgery within the past six months, (4) the inability to walk, and (5) pregnancy.

Instrumentation

Gait temporal-spatial parameters were captured during all tasks for kinematic calculation with a Vicon six-camera, three-dimensional motion analysis procedure recording at 120 Hz, (Vicon Motion System, Denver, CO). Through observing a plug-in-gait model embedded in the VICON software, an entirety of 15 retro-reflective markers were situated on anatomical landmarks on the subjects' lower limbs and pelvis to define the body segments.

Gait protocol

Subjects performed all the assigned gait tasks barefoot within the gait laboratory while clothed in shorts and a t-shirt. Following a demonstration by a research crew member, subjects were allowed to practice the gait task three times to get acquainted with the tasks and laboratory setting. Each practice session was segregated by a rest interval of at least one minute to avoid fatigue. All subjects conducted three gait tests (even, ramp, and stair) in differing randomized orders to prevent fatigue. Each gait task was performed three times, with a recess interval of at least one minute between examinations.

Before executing the protocol (even, ramp or stair), subjects were instructed to stand behind a line marked on the floor. Upon hearing the word "*go*", participants executed one of the following at their preferred gait speed:

Even surface (Timed up and go test-TUG)

Subjects walked over a distance of 10 feet, made a U-turn, and walked back to the starting point.

Ramp protocol
Participants walked over a distance of 2.44 meters to the wooden ramp (20.32 cm in height), ascended it, walked to the end of the level platform (length: 213.36cm, width: 111.76cm), made a u-turn, descended the ramp back to ground level, and walked back to the starting point.

Stair protocol
Subjects walked over a distance of 2.44 meters to the wooden stair step (20.32 cm in height), ascended it, walked to the end of the level platform (length: 213.36cm, width: 111.76cm), made a u-turn, descended the stair step, and walked back to the starting point.

Data analysis
The spatio-temporal variables (Table 2) consisted of stride time, step time, opposite foot swing phase, opposite stance phase, the gait of speed, cadence, stride length, step length, single-limb support period, and double limb support among others. The SPSS® Statistics v25.0.0 Program (IBM® Corporation, Armonk, New York, USA) was applied for all statistical analyses. This examination intended to ascertain the variations while shifting from a flat surface to ascending and descending a ramp and a stair-step within each group. It is our understanding identifying said adjustments can serve in recognition of early gait affected variables. Accordingly, referred to the last point, a repeated-measures ANOVA was accepted as analytical tests to characterize the even walkway criteria to the ramp and the stair variables within each group. Statistical significance was conducted at a p-value less than or matched to .05.

RESULTS

Table 1 illustrates the demographic profile of the subjects who participated in this study. Both groups were analogous in age, sex, height, weight, cardiovascular status, and BMI. Table 2 illustrates the tempo-spatial gait parameters on the even surface (TUG) in comparison to ascending and descending both the ramp and the stair between the cDMII and CoG groups. During the totality of the gait cycle, both groups were comparable for opposite foot swing phase and opposite foot stance phase. However, upon exploring the swing phase of the reference limb, the cDMII group exhibited different adaptations compared to the control group. The cDMII subjects showed similar adaptation while descending the stair with a shorter adjustment percentage while ascending the ramp.

Table 1: Demographic and clinical variables (mean ± standard deviation).

Group	cDMII (N = 15)	CoG (N = 15)	p
Age (years)	57.7 ± 5.1	56.0 ± 4.7	.39
Height (inches)	65.8 ± 4.3	64.5 ± 3.9	.59
Weight (pounds)	176.6 ± 75	162.2 ± 8.6	.27
Body mass index (kg/m^2)	28.6 ± 3.3	26.6 ± 3.1	.13
HbA1c (%)	6.7 ± 0.5	N/A	N/A
Years following diagnosis of diabetes	8.0 ± 5.8	N/A	N/A

Results of Student's t-test performed between the two sample groups: controlled diabetic group without peripheral neuropathy (cDMII); healthy non-diabetic control group (CG). Significance threshold = $p \leq .05$; significant p = threshold value; non-significant p = calculated value; NA = not applicable.

Table 2. Spatiotemporal variables during TUG, stair and ramp (mean ± SD). Results of ANOVA for the comparison of gait variables within tasks.

Gait variables	cDMI-Tasks		Avg	p-Value	CoG-Task		Avg	p-Value
Cadence (steps/min)	TUG 103.2 ± 8.1	STA	84.7 ± 6.9	.001	TUG 107.9 ± 7.4	STA	91.97 ± 12.9	.001
		STD	81.2 ± 7.1	.001		STD	88.4 ± 7.3	.001
		RA	94.8 ± 8.0	.06		RA	96.7 ± 12.4	.005
		RD	92.6 ± 8.8	.95		RD	99.5 ± 12.0	.033
Stride Time (seconds)	TUG 1.08 ± 0.1	STA	1.2 ± 0.1	.81	TUG 1.05 ± 0.08	STA	1.1 ± 0.12	.163
		STD	1.2 ± 0.1	.05		STD	1.2 ± 0.09	.005
		RA	1.1 ± 0.1	1.0		RA	1.05 ± 0.17	.92
		RD	1.1 ± 0.1	1.0		RD	1.02 ± 0.11	.63
Opposite Foot Swing Phase (percent)	TUG 4.6 ± 2.2	STA	4.9 ± 6.7	.85	TUG 6.7 ± 4.3	STA	3.6 ± 4.5	1.0
		STD	9.0 ± 5.9	0.05		STD	3.6 ± 5.3	1.0
		RA	9.1 ± 7.1	0.05		RA	13.8 ± 24.1	1.0
		RD	8.5 ± 5.1	0.76		RD	12.2 ± 23.6	1.0
Opposite Foot Stance Phase (percent)	TUG 47.2 ± 1.1	STA	40.7 ± 4.0	.001	TUG 47.7 ± 1.3	STA	41.4 ± 7.06	.001
		STD	41.2 ± 6.9	.001		STD	44 ± 2.84	.05
		RA	43.2 ± 4.9	.16		RA	456 ± 2.7	.14
		RD	46.9 ± 1.8	1.0		RD	47.4 ± 3.4	.81
Step Time (seconds)	TUG 0.5 ± 0.03	STA	0.61 ± 0.06	.001	TUG 0.51 ± 0.04	STA	0.59 ± 0.06	.001
		STD	0.51 ± 0.07	1.0		STD	0.50 ± 0.04	.60
		RA	0.53 ± 0.05	1.0		RA	0.54 ± 0.07	.13
		RD	0.50 ± 0.06	1.0		RD	0.46 ± 0.07	.06
Single Limb Support (seconds)	TUG 0.4 ± 0.17	STA	0.33 ± 0.36	1.0	TUG 0.22 ± 0.3	STA	0.23 ± 0.40	.94
		STD	0.40 ± 0.32	.001		STD	0.38 ± 0.49	.05
		RA	0.43 ± 0.09	1.0		RA	0.47 ± 0.9	.05
		RD	0.44 ± 0.17	1.0		RD	0.52 ± 0.13	.01
Double Limb Support (seconds)	TUG 0.10 ± 0.6	STA	0.08 ± 0.16	1.0	TUG 0.04 ± 0.10	STA	0.06 ± 0.13	.74
		STD	0.10 ± 0.17	.001		STD	0.07 ± 0.09	.05
		RA	0.13 ± 0.06	1.0		RA	0.20 ± 0.29	.001
		RD	0.10 ± 0.06	1.0		RD	0.10 ± 0.05	.25
Reference Limb Swing Phase (percent)	TUG 53.9 ± 1.96	STA	47.9 ± 4.8	.001	TUG 53.5 ± 2.04	STA	47.7 ± 6.3	.001
		STD	50.4 ± 4.2	.22		STD	48.7 ± 2.8	.001
		RA	49.0 ± 4.4	.01		RA	51.3 ± 2.9	.11
		RD	52.7 ± 3.8	1.0		RD	51.8 ± 3.8	.22
Stride Length (meters)	TUG 1.05 ± 0.09	STA	0.97 ± 0.14	1.0	TUG 1.03 ± 0.12	STA	0.94 ± 0.16	.10
		STD	0.83 ± 0.21	.01		STD	0.81 ± 0.18	.001
		RA	1.02 ± 0.16	1.0		RA	1.08 ± 0.14	.44
		RD	0.86 ± 0.18	.04		RD	0.88 ± 0.14	.001
Step Length (meters)	TUG 0.51 ± 0.03	STA	0.42 ± 0.06	.05	TUG 0.51 ± 0.06	STA	0.43 ± 0.07	.001
		STD	0.45 ± 0.09	.44		STD	0.44 ± 0.09	.01
		RA	0.48 ± 0.08	1.0		RA	0.52 ± 0.06	.59
		RD	0.43 ± 0.10	.10		RD	0.44 ± 0.08	.01
Walking speed (meters/seconds)	TUG 0.92 ± 0.11	STA	0.70 ± 0.12	.001	TUG 0.94 ± 0.09	STA	0.73 ± 0.15	.001
		STD	0.59 ± 0.16	.001		STD	0.61 ± 0.16	.001
		RA	0.83 ± 0.17	1.0		RA	0.91 ± 0.14	.54
		RD	0.73 ± 0.20	.05		RD	0.75 ± 0.15	.001

cDMII: control diabetics. CoG: control subjects, TUG: even walkway, STA: stair ascending, STD: stair descending, RA: ramp ascending, RD: ramp descending. SD: standard deviation, Avg: average. Significance boundary = p < .05; significant p = boundary value; non-significant p = calculated value.

Additionally, the cDMII group and CoG demonstrated similar walking speed adaptations across tasks. Nevertheless, during ramp ascension, the cDMII group was unable to reduce cadence, thus revealing the lack of gait modifications when imposed with a different, more challenging surface. An inability to adapt step length was observed in the cDMII group upon descending the stair step. The cDMII group also exhibited resemblances in adaptation when juxtaposed to the results of the CoG in stride and step time. With this, the vast difference in the absence of adaptation while changing surfaces were shown in single limb support during ascending and descending the ramp surface. Contrarily, the cDMII group's demonstration of double limb support was distinct from the CoG as they lacked adaptation while ascending the ramp surface.

DISCUSSION

Given the insufficiency of published literature with similar specifications, this research study intended to establish the gait variations present in controlled diabetics with no noticeable gait difficulty. As gait alterations and conflicts are further evident when shifting to a more compound surface, such as a slope or steps, we explored the temporospatial gait parameter variations from an even-surfaced walkway, to ascending and descending both a slope and a stair-step in Hispanic-Latino individuals with controlled type II diabetes mellitus. While temporospatial parameters were parallel for both groups, some normal gait adaptations were more evident in the control group. The slight absence of gait adaptations in the cDMII group during the stair and ramp tasks demonstrate how diabetes can lead to irregularity in gait patterns, even in controlled diabetics.

The altered swing phase percentage from the reference limb in the cDMII group during the stair descent (STD) and ramp ascent (RA) tasks is comprehended as a result of the complex nature of the tasks compared to walking on a level surface. The higher swing phase percentage present in the cDMII group more so than the CoG during STD could be attributed to postural instabilities, considering that STD is a challenging task that requires adaptations in motor activation patterns and force absorption (Riener et al., 2002). In order to maintain postural balance in the stance phase of STD, the plantar flexors must eccentrically contract for weight acceptance. In contrast, the knee extensors have to contract smoothly to descend the stairs eccentrically (McFadyen & Winter, 1988). The swing phase of STD requires higher hip and knee flexion than even-surface level walking, as well as the co-contraction of the ankle muscles in order to clear the foot and prepare for the next step. Accordingly, a study by Handsaker and colleagues (2014) depicts that participants with diabetes, particularly those with neuropathy, exhibited altered muscle activation and slower force generation of the knee and ankle during STD and stair ascension (STA).

Therefore, we infer that our cDMII group presented deviations to the normal muscle activation patterns, thus emanating distinct Spatio-temporal characteristics despite the absence of neuropathy. The shorter percentage for the swing phase adjustment of the reference limb during RA compared to levelled walking could also be attributed to altered activation patterns found in the cDMII participants. Even though we did not utilize an electromyograph system to interpret the electrical activity of the muscles responsible for the gait deviations found in the cDMII group, our findings suggest that the variant activation patterns affect normal postural muscle activation during stair and ramp tasks. Additionally, during the swing phase, the contralateral leg is required to have enough stability to maintain balance by activating the ankle and hip abductor muscles to allow the swinging leg to proceed forward. Examining how walking on a ramp entails more muscle activation, especially to counteract the force of gravity at an inclination, maintaining balance on one leg proves more challenging than a bipedal stance. Justifiably, we found that the cDMII participants reduced their swing phase time during RA to maintain postural stability, which could be a result of a mechanism for compensation in avoiding the demands of upholding a single leg stance.

There are deviations in temporospatial parameters found from our investigation that are distinctive from previous literature. The inability to decrease cadence during RA and to adjust step length effectively during STD in the cDMII group signifies an absence of conformity to normal gait adaptations. Previous investigations have predicted that the walking performance decreases among cDMII patients upon the introduction to different surfaces; these decreases can be seen in patients' decreased gait speed while walking on grass in comparison to a tar surface, and even more so while walking on a stone surface (Allet et al., 2009). Other researchers have identified gait deviations in diabetic patients during stair tasks, such as slower gait speed, reduced ankle and knee range of motion, decreased plantarflexion strength, and unsteadiness (Dingwell et al., 2000; Handsaker et al., 2014; Yavuzer et al., 2006). Contrary to our research findings, Yavuzer and colleagues identified slower cadence, shorter step length, and longer double limb support time in diabetic patients, both with and without PN. However, their participants had advanced cases of uncontrolled diabetes and further deviations in gait during level walking (Yavuzer et al., 2006).

We anticipated that our cDMII participants would demonstrate differences in specific variables, such as gait speed during stair or ramp. Both tasks require more gait and postural adaptation and are more physically demanding than level walking. While our cDMII participants did decrease their gait speed during inclined surface tasks, the CoG demonstrated similar adjustments. Nevertheless, since our cDMII participants' demographic factors equivalent to those of the CoG, the overall gait performance of the cDMII participants is comparable to those of healthy individuals. Therefore, our cDMII participants can refrain from compensatory strategies to walk effectively across different surfaces, such as a ramp inclination of 14.4°, which is a similar inclination used in various other studies (Kawamura et al., 1991; Lay et al., 2006; McVay & Redfern, 1994; McIntosh et al., 2006; Redfern & DiPasquale, 1997; Wall et al., 1981). However, increasing the ramp inclination or the stair-step's height can prove more physically demanding, allowing for a more distinct display of modifications in spatiotemporal variables that are unique to those with cDMII.

Increased double limb support (DLS) timing observed across the different tasks as more apparent in the cDMII group. Our research findings corroborate prior studies that have found decreased single limb support (SLS), yet increased DLS timings in diabetic patients during different stages of the condition (Petrofsky et al., 2005; Yavuzer et al, 2006; Wrobel & Najafi, 2010). Increasing DLS time is a way to increase stability under demanding gait conditions; however, the DLS time for cDMII subjects proved to be less than expected during RA, which can be a result of early undetected motor and sensory changes associated with DMII. The decrease in SLS and DLS time in cDMII participants during RA explains why cadence increased during RA; abnormal motor patterns such as delayed activation of gastrocnemius during midstance and delayed activity of rectus femoris and gluteus medius during terminal swing have been identified in non-neuropathic diabetic subjects during level walking (Sawacha et al., 2012). Another study by Rosario et al. (2020) revealed increased anterior-posterior sway during static balance in cDMII subjects, inferring that early signs of postural instability are attributed to challenged proprioceptive and vestibular inputs. Furthermore, inconsistent kinematic and kinetic parameters have also been discerned in cDMII participants when compared to control groups (Hazari et al., 2016). Thus, we propose that the deviations mentioned above in gait and balance characteristics during level walking will prove further distinction upon the addition of more demanding surfaces, such as a ramp with increased elevation. Variations in postural and gait mechanisms in cDMII participants during ramp tasks can, in turn, affect their SLS and DLS time, which imposes greater postural instability.

Postural instabilities related to DMII result from multiple risk factors which may be incipient in early stages yet become more evident as the disease progresses. With the advancement of the disease and its complications, such as neuropathy and motor changes, patients exhibit decreases in stride length and gait

speed and abnormal muscle activation patterns that can lead to an increased risk of falls (Dingwell et al., 2000; Allet et al., 2009; Kawamura et al., 1991). Morphological changes, such as glycosylation in the foot, can present as hardened skin with thinner fat pads, thickened tendons, muscular atrophy, delayed muscle activation, and decreased bone density, putting diabetic patients at further risk for foot ulcerations (Wrobel & Najafi, 2010). Likewise, changes in autonomic function related to DMII can affect the quality of gait and hinder local blood flow (Petrofsky et al., 2005). As such, abnormal gait patterns can result in elevated plantar pressure in diabetic foot ulcers, causing additional adverse effects on the healing process (Fernando et al., 2016). Risk factors, such as autonomic dysfunction and peripheral arterial disease, can also progress if DMII is insufficiently controlled, further affecting patients' gait performance. With this, some of the aforementioned distinct gait parameters and anatomical changes can remain unaffected or undetected in the early stages of diabetes, as was the case for our participants. However, early identification and interventions can foster methods to palliate the complications of DMII, reduce the fall risk, improve quality of life, and lower medical costs for those afflicted with the disease.

CONCLUSION

This study intended to discern the variations in gait on specific surfaces among diabetic patients with controlled glucose levels without peripheral neuropathy. This investigation ushers on the recognition of gait adaptations among diabetes subjects who have related standards to individuals without the disease. Frequently, akin investigations focus on further advanced stages of the condition where other difficulties might be responsible for observed changes, such as peripheral neuropathy, diminished blood circulation, or ulcers. However, this inquiry fixated upon the earlier stages of diabetes, a point where the condition is contained by physical activity, diet, and medication. The outcomes of this study allude to an introductory reduction of the capability to be dynamically balanced while walking and adapting to distinct surfaces. Taking our outcomes into consideration, we encourage clinicians who work with diabetics to assess their patients' gait, especially that of single and double limb support, without excluding patients who are asymptomatic. Additionally, we advise implementing dynamic balance training to all individuals with diabetes, such as a single-limb balance and shifting stance tasks. Likewise, physical therapists and other applicable clinicians should inform their patients' primary care providers about recommending balance programs for diabetic patients during the early stages of the disease to be more proactive rather than reactive in treating future complications. Further inquiries should evaluate the impact of dynamic and static balance training on gait in cDMII patients and whether training single leg balance can positively alter gait performance. Finally, prospective studies should contemplate investigating neuromuscular and kinematic parameters, along with their imposition of modifications upon gait while on differing surfaces in order to explore further the initial adjustments found in those with diabetes as a result of the disease.

AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design.

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DISCLOSURE STATEMENT

Authors report no conflict or competing interest.

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