Original Article

Evaluating static postural control in subjects with controlled-diabetes mellitus II

MARTIN G. ROSARIO[1], ANEESAH HYDER[2], ELIZABETH OROZCO[1], JOSÉ G. VÉLEZ BARTOLOMEI[3], CARLOS LEBRÓN QUIÑONES[3], FLAVIA BAYRON[3]

[1]*School of Physical Therapy, Texas Woman's University, Dallas, Texas, United States of America*
[2]*College of Health Sciences, Texas Woman's University, Denton, Texas, United States of America*
[3]*School of Health Professions, University of Puerto Rico, San Juan, Puerto Rico, United States of America*

ABSTRACT

Diabetes and neuropathy have been linked to postural instability. Aims: The purpose of this study is to determine how each system involved in balance is affected when challenged in a static standing posture. The goal was to identify postural instability by measuring balance through the amount of sway and weight bearing distribution in non-neuropathic controlled type II diabetics. Methods: Twelve participants (five males and seven females) with controlled type II diabetes mellitus and no history of peripheral neuropathy (Non-PN cDMII) formed the diabetic group, whereas eighteen participants (7 males and 11 females) without type II diabetes formed the control group. The exclusion criteria was applied via a series of screening tests (Berg Balance Scale, Five Times Sit To Stand Test, Functional Reach Test and Monofilament Test). Postural stability and weight distribution during quiet standing were measured using a Tekscan Matscan pressure mat, which measured the amount of sway and weight distribution. Static postural control was evaluated during eight sensory conditions that perturbed or stimulated the visual, proprioceptive, and vestibular systems. Results: Postural control was found to be significantly deficient when the vestibular system was stimulated, whereas the proprioceptive system was perturbed. After the data analysis, there was a significant difference in antero-posterior sway (P=0.05) with the following tasks: eyes open with head movements on an unstable surface, and eyes closed with head movements on a firm surface. Conclusions: The results revealed that the experimental group with type II diabetes had greater postural instability when compared to the control group during tasks with the vestibular system on an unstable surface. This demonstrates that, due to their deficits, individuals with non-PN cDMII are unable to maintain their balance when the vestibular and proprioceptive

Corresponding author. *School of Physical Therapy 5500 Southwestern Medical Ave. Dallas, TX 75235. United States of America.*
E-mail: mrosario1@twu.edu
Submitted for publication February 2019
Accepted for publication April 2019
Published *in press* June 2019
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202

doi:10.14198/jhse.2020.152.09

systems are challenged simultaneously. **Keywords:** Diabetes; Static balance; Sways; Centre of pressure; Pressure mat; Weight distribution.

Cite this article as:
Rosario, M.G., Hyder, A., Orozco, E., Vélez, J.G., Quiñones, C.L., & Bayron, F. (2019). Evaluating static postural control in subjects with controlled-diabetes mellitus II. *Journal of Human Sport and Exercise*, *in press*. doi:https://doi.org/10.14198/jhse.2020.152.09

INTRODUCTION

Static postural control is characterized by the ability to maintain the body's centre of mass (COM) within the individual's base of support (BOS). Balance requires the help of different body systems such as: vestibular, visual, proprioceptive and musculoskeletal (Brenton-Rule et al., 2012). Certain diseases, such as Type II Diabetes Mellitus (DMII), can cause severe neuropathy, loss of vision, and an array of other symptoms that can affect the different systems involved in balance. The importance of assessing functional static balance is that we can identify and reduce the risk of falls in patients with diabetes, thus preventing secondary complications such as fractures and soft tissue injuries (Wallace et al., 2002) that may further impair the systems' needed to maintain static postural control.

According to the Center of Disease Control (CDC), over 100 million U.S. adults are now living with diabetes or prediabetes. Data from 2015 revealed that 30.3 million Americans, which composed 9.4 percent of the U.S. population, have diabetes (www.cdc.org). DMII is the leading cause of blindness in adults over the age of 40; among these individuals, 5.4% of patients with DMII are 40 years and older and were diagnosed with diabetic retinopathy (www.visionproblemsus.org). Diabetic retinopathy affects the visual input, thus affecting balance and postural control. Additionally, between 60%-70% of individuals with DMII experience mild to severe damage to the nervous system (www.cdc.org). Furthermore, 30% of individuals greater than 40 years of age with diabetes have sensory deficits in their feet. As a result, the prevalence of falls in patients with diabetes in 2012 was 18.8%, with 79.6% of these cases resulted in mild tissue injury (Azidah AK, Hasniza H & Zunaina., 2012).

Therefore, the deficits that arise from this disease can affect the functionality and independence of individuals living with DMII. Complications that have been associated with the disease are muscle weakness (Bonnet & Ray C, 2011),vestibular (Agrawal Y et al., 2010), visual, proprioceptive, (Simoneau G et al., 1999), and sensory deficits (Bonnet & Ray C, 2011). These impairments can affect functional balance, centre of pressure displacement, and amount of sway, resulting in postural instability and an increase risk for falls (Maurer et al., 2005).

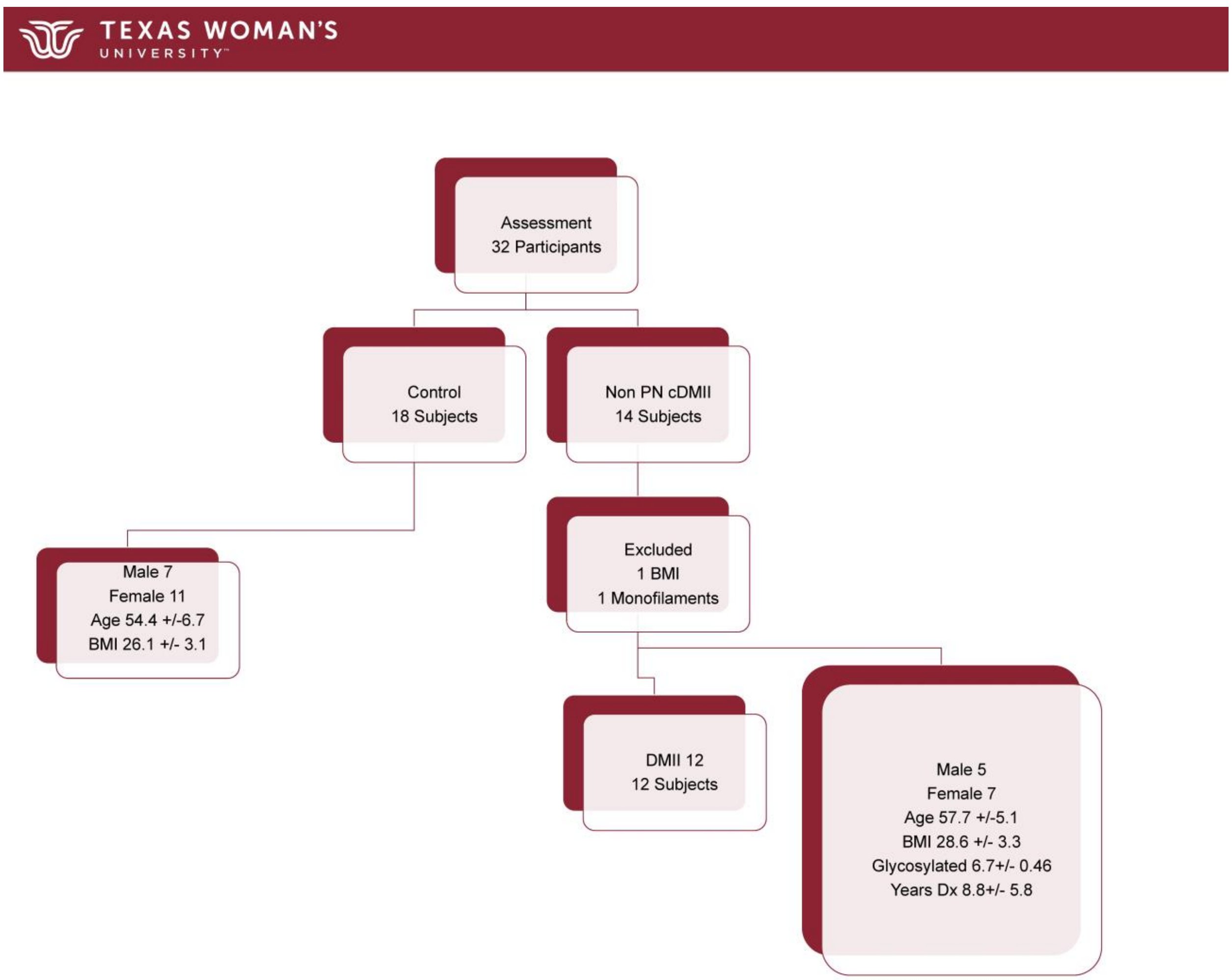
Lafound et al., (2004) found that the participants with diabetes and sensory neuropathy had greater antero-posterior and medial-lateral sway when compared to participants without diabetes (Thapa P et al., 1996). Given their results, the authors reinforce the importance of focusing on postural control, especially in the medial-lateral direction. In their literature review, Bonnet C et al., (2011), 26 articles about the kinematics of postural behaviour in participants with diabetes were evaluated. Their findings indicated that the participants with diabetic neuropathy swayed more than the participants without diabetes when in a standing position. These sways increase when disturbing the different sensory systems, in which the participants with diabetes present more postural instability.

With the information that has been discussed, we can summarize that static postural control can be severely affected in people with DMII; however, neuropathy and other diabetic complications can contribute to the deficits that occur in the vestibular, visual and proprioceptive systems. These deficiencies could result in balance problems that can be demonstrated as an enlargement in postural sway, thus increasing the risk of falls. Also, it is not clear which sensory system is affected first, and to what degree the impairment each sensory system experiences in comparison to the others. It is essential to know which system(s) are most affected in this disease and in which situations these systems work most efficiently in people with controlled (glucose levels within a normal range in the last three months) diabetes without neuropathy. Therefore, the purpose of this study is to identify changes in postural control in people with controlled diabetes without neuropathy and make an individual comparison of each system affected during standing balance while making different associations between those systems.

METHODS

Ethical statement

The study procedure was approved by the Institutional Review Board of the University of Puerto Rico Medical Sciences Campus (Protocol A2540313). Each participant read and signed an informed consent form subsequent to being educated on the risks, their rights, and possible discomforts they may encounter while taking part in this study. This work was conducted at a Physical Therapy Laboratory affiliated with the School of Health Professions at the University of Puerto Rico Medical Sciences Campus.



Note. Control = Control Subjects; non-PN cDMII = Subjects with Diabetes Mellitus Type 2; BMI = Body Mass Index; BBS = Berg Balance Scale; FR = Functional Reach; Monofilaments = Monofilaments Test; Years Dx = Years Diagnosed with Diabetes Mellitus Type 2.

Figure 1. Demographical Data.

Subjects

Twelve adults with controlled diabetes and no history of peripheral neuropathy (non-PN cDMII) (five males and seven females; age=57.7± 5.1 years, height 167.1±4.3 cm, mass 80.1±34.3kg) formed the experimental diabetic group (8.0±5.8 years with the diagnosis of DMII). Eighteen healthy adults (seven males and eleven females, age=54.4± 6.7 years, height 164.8±3.9cm, mass 73.6± 28.9 kg) formed the control group (CG) (for participant enrolment, see Figure 1). Both groups were selected homogeneously as per sex, age, body mass index, and level of physical activity (Table 1). Participants in the diabetic group were classified as having controlled diabetes. According to the American Diabetes Association, controlled diabetes is defined as individuals with a glycosylated haemoglobin level of 7.5% or less.

Table 1. Clinical and demographic data (mean ± standard deviation) of the non-peripheral neuropathy controlled type II diabetes group (non PN cDMII) and healthy non-diabetic control group (CG).

	Non PN cDMII (N=14)	**CG (N=18)**	**P-value**
Age (years)	57.7 ± 5.1	56.0 ± 4.7	0.39
Height (cm)	167.1 ± 4.3	164.8 ± 3.9	0.59
Weight (kg)	80.1 ± 34.3	73.6 ± 28.9	0.27
BMI	28.6 ± 3.3	26.6 ± 3.1	0.13
HbA1c	6.7 ± 0.5	NA	NA
Years following diagnosis of diabetes	8.0 ± 5.8	NA	NA

Note: Results of Student's t-test performed between the two groups. Significance threshold = P <0.05; NA=not applicable.

We utilized flyers to promote the study and snowball sampling was used to recruit participants. In Figure 1, the general process of participant selection and the demographic data of the groups can be observed. The exclusion criteria designed for both groups were as follows:

- Age (male and female): 40-65 years old.
- Physical conditions: No back or lower extremity surgery or lesion in the past six months. No lower extremity amputations or ulcers.
- If female: Not pregnant.
- Weight: BMI must be 30 or below (normal to overweight).

In addition to the inclusion and exclusion criteria, as well as to ensure that the two groups were homogenous, all subjects utilized the same protocol implemented by Rosario MG, Orozco E, Babilonia N et al., (2018) that included, body mass index (BMI), standard anthropometric measurements and AHA/ACSM Health/Fitness (Balady et al., 1998) participation questionnaire.

Clinical Evaluation

Due to the nature of the balance test and to ensure that participants could safely take part in this study, all subjects were further screened according to Rosario MG, Orozco E, Babilonia N, et al., (2018) clinical criteria. Additionally, the following was also performed as criterion:

Ø Berg Balance Scale: The Berg Balance Scale has a total score of 56 points and we expect our groups to show a score of 41-56, indicating the individual is at low risk for falls and therefore, can be included in this study (Berg K et al., 1995).

Ø Functional Reach Test: The objective is to evaluate postural stability by measuring the maximum distance that the subject can reach while standing static. If the subject reaches <14.9cm (male), <13.2cm (female) he/she will be excluded from the study due to the predisposition to falls (Duncan et al., 1990).

Ø Romberg Test: For this test, the subject will stand with their feet together and **eyes closed for 30 seconds.** If the subject loses balance, they will test positive for proprioceptive deficits and therefore, the individual would be excluded from the study (Bohannon et al., 1984).

Materials
After screening each participant for predisposing fall risks, the groups were formed and balance tests were conducted. The participants were asked to stand on the MatScan™ pressure mat (TekScan, Boston, MA) (Brenton-Rule A et al., 2012). This mat contains sensors that measure the body sways anteriorly (forward), posteriorly (backward), and laterally (sideways). The data collected from the pressure mat will be analysed with Tekscan Sway Analysis Module (SAM) software designed for this purpose.

Procedures
Each subject was instructed to stand with a static bipedal posture for 30 seconds on the MatScan© pressure mat and perform eight balance tasks. We randomized the order of the tasks per subject. For each eye open trial, the subjects were instructed to fix their gaze on a stationary target in the centre of their field of vision. Participants performed the following eight balance tests: while standing on a foam mat, eyes open (EO), eyes closed (EC), eyes open while moving head up and down (EOHUD), and eyes closed while moving head up and down (ECHUD), then while standing on a stable surface, eyes open (EO), eyes closed (EC), eyes open while moving head up and down (EOHUD), and eyes closed while moving head up and down (ECHUD) (Rosario MG, Collazo H, Mateo M et al. 2017 and Rosario MG, López L, Méndez M, et al., 2018).

Analysis
The data for the A-P and M-L sway and weight bearing distribution outcome measures were analysed by the statistical analysis system SPSS version 20. The non-parametric statistical analysis used was the Mann-Whitney U Test to evaluate non-normative and extensively variable data. A P-value of < 0.05 was considered significant in this study.

RESULTS

The screening tests were done to homogenize both populations so comparisons could be done between the two. For the Berg Balance Scale, the control group scored 55.3 ± 1.6, whereas the non-PN cDMII group scored 53.4 ± 2.6. During the Functional Reach Test, the control group scored 13.3 ± 2.3 while the non-PN cDMII group achieved a score of 12.5 ± 2.9. In the monofilament test, both groups felt a monofilament with less than 5.07g of force. The BMI data can be observed in Figure 1 for both groups. These tests demonstrated that the two groups were comparable and were at minimal risk of falling.

After analysing the data, no significant differences were found in medial-lateral sway (Table 3) and weight distribution forces (Table 4) in all balances tasks between the non-PN cDMII group and control group. Results showed a significant increase in antero-posterior sway when the subjects performed head flexion and extension with their eyes closed (EC HUD) on firm surface, and head flexion and extension with their eyes open while standing on a foam mat (MAT EO HUD).

Table 2. Statistical analysis of antero-posterior sway displacement (cm2) results with their mean, standard deviation, and significance of control in Diabetes Mellitus Type 2 groups in the following eight balance tasks: eyes open (EO), eyes closed (EC), movement of the head up and down (HUD), and standing on a foam mat (Mat).

Balance Test Condition	Control Mean ±	Non PN cDMII Mean ±	Sig. P< .05
EO	1.9 ± 1.0	2.2 ± 0.7	0.07
EC	2.1 ± 1.0	2.7 ± 1.1	0.10
EO HUD	2.3 ± 0.8	2.7 ± 0.8	0.28
EC HUD	2.6 ± 1.1	3.7 ± 1.6	0.05
Mat EO	5.3 ± 1.5	5.2 ± 2.3	0.98
Mat EC	7.2 ± 3.4	8.9 ± 2.5	0.08
Mat EO HUD	8.3 ± 2.6	10.3 ± 2.7	0.05
Mat EC HUD	12.3 ± 2.6	12.2 ± 4.2	1.0

Significance threshold = P ≤ 0.05.

Table 3. Statistical analysis of medial-lateral sway displacement (cm2) results with their mean, standard deviation, and significance of control in Diabetes Mellitus Type 2 groups in the following eight balance tasks: eyes open (EO), eyes closed (EC), movement of the head up and down (HUD), and standing on a foam mat (Mat). No significant difference was found.

Balance Test Condition	Control Mean ±	Non PN cDMII Mean ±	Sig. P< .05
EO	1.61 ± 3.3	1.3 ± 1.6	1.0
EC	0.92 ± 0.6	0.99 ± 0.6	0.85
EO HUD	1.51 ± 2.4	1.04 ± 0.4	0.91
EC HUD	1.86 ± 2.8	1.34 ± 0.6	0.95
Mat EO	5.39 ± 4.1	4.83 ± 2.2	0.95
Mat EC	7.82 ± 5.2	6.78 ± 3.5	0.72
Mat EO HUD	5.64 ± 2.6	7.43 ± 3.8	0.08
Mat EC HUD	7.84 ± 2.9	9.23 ± 4.2	0.31

Significance threshold = P ≤ 0.05.

Table 4. Statistical analysis of Weight Bearing Distribution results (percentage) comparison of the right foot (RT) and the left foot (LT) results with their mean, standard deviation, and significance of control in Diabetes Mellitus Type 2 groups in the following eight balance tasks: eyes open (EO), eyes closed (EC), movement of the head up and down (HUD), and standing on a foam mat (Mat). No significant difference was found.

Balance Test Condition	Control Mean ±	Non PN cDMII Mean ±	Sig. P< .05
EO WB LT	49.2 ± 4.73	52.1 ±4.15	0.95
EO WB RT	50.7 ± 4.73	47.8 ± 4.15	0.95
EC WB LT	50.0 ± 3.65	51.5 ± 3.18	0.74
EC WB RT	51.6 ± 7.25	48.4 ± 3.18	0.30
EO HUD WB LT	48.4 ± 3.43	47.9 ± 4.60	0.50
EO HUD WB RT	52.9 ± 6.47	52.1 ± 4.60	0.53
EC HUD WB LT	49.5 ± 3.48	49.1 ± 5.73	0.12
EC HUD WB RT	52.0 ± 6.24	50.9 ± 5.73	0.79
Mat EO WB LT	48.8 ± 12.30	47.6 ± 11.35	0.83
Mat EO WB RT	53.8 ± 16.85	52.4 ± 11.35	0.43
Mat EC WB LT	47.6 ± 11.59	53.4 ± 11.35	0.29
Mat EC WB RT	52.3 ± 11.59	46.6 ± 9.10	0.29

Mat EO HUD WB LT	44.1 ± 8.81	50.4 ± 8.00	0.94
Mat EO HUD WB RT	55.8 ± 8.81	49.6 ± 8.00	0.94
Mat EC HUD WB LT	42.7 ± 9.20	50.8 ± 9.69	0.96
Mat EC HUD WB RT	57.2 ± 9.20	49.3 ± 9.69	0.96

Significance threshold = $P \leq 0.05$.

DISCUSSION

The purpose of this study was to identify postural control deficits in people with controlled diabetes without neuropathy to make an individual comparison of each sensory system involved in balance that was affected while standing. In their study, Toosizadeh et al. (2015) mentioned the severity of the condition is associated with more postural instability in this population. Therefore, when PN is present and the visual input is absent (eyes closed test), these individuals exhibited an abnormal postural strategy, depicting greater postural instability compared to individuals with diabetes alone. Palma et al. (2013) linked the association of the advancement of diabetes with poor instability, thus, the more advanced the condition, the more significant the postural instability will be. In this study, we assessed A-P and M-L sway, along with weight bearing distribution during eight sensory conditions designed to challenge or cancel the different inputs that control balance: vision, vestibular, and proprioception. Results showed that subjects with non-PN cDMII swayed more than the control group while standing on a foam mat (which perturbs the proprioceptive system) eyes open with head movements head (thus stimulating the vestibular system). This increase in sway can be interpreted as the vestibular inputs are not functioning appropriately to help the subject maintain optimal balance.

This finding can be compared to Bonnet and Ray's systematic review (2011) in which it was revealed that peripheral neuropathy might not be the sole significant cause of an increase in postural sways in individuals with DMII. With this, the proprioceptive system is likely not the only system that affects static balance in patients with DMII. This reinforces the results found in this study, as the participants of the Non-PN cDMII group did not present with peripheral neuropathy, though differences in postural sway remained present. In contrast with the study by Simoneau and colleagues (1995), which found that there were no significant differences in the systems that perturbed vision and the vestibular system, our study reflects that patients with Non-PN cDMII without neuropathy presented postural changes in the standing position.

During the MAT EOHUD task, the Non-PN cDMII group had a significant increase antero-posterior sway ($P= 0.05$) in comparison to the control group. In this task, vestibular and proprioceptive systems were perturbed with the visual system intact, where the subjects with DM did not demonstrate proper dominion over them. In a similar study in which they perturbed the visual and proprioceptive system, Simoneau and colleagues (1995) did not find statistically significant differences, so they do not attribute the deficits to these sensory systems. Our study found that subjects with Non-PN cDMII are dependent on their visual system, and this system is either deficient or not enough to maintain individuals' proper standing balance.

Furthermore, we can observe greater sways in the antero-posterior direction in the Non-PN cDMII group, which led us to identify that this group created higher dorsiflexion as a compensatory mechanism to maintain postural control. This finding can convey that the ankle strategy is mostly present in this group. However, Ahmmed and colleagues (2003) indicated that there was no significant difference in A-P sways during EO and EC task when comparing the diabetes without neuropathy group to the control group. In contrast, our study did observe changes in the population with Non-PN cDMII when perturbing the three sensory systems.

In the task in which the visual and vestibular systems were perturbed, there was a significant difference of P≤0.05 found in subjects with Non-PN cDMII when compared to control subjects. An intriguing find was that in the MAT EC HUD task, there was no significant difference discovered (P= 1.00). Lafound and colleagues (2004) indicated that when the visual system was the only system perturbed (i.e., eyes closed), there was higher antero-posterior displacement in the group with DMII when compared to participants without DMII. Our study demonstrates that the group with Non-PN cDMII have increased deficiencies when using their proprioceptive system, as this system does not compensate to maintain static postural control. Instead, these individuals rely solely on their visual system for this objective. Under these circumstances, it appears that the participants with Non-PN cDMII may use ankle strategies to help maintain their standing balance as the proprioceptive system is not enough to maintain this control.

We collected the data that represents the weight distribution from the left and right foot; this study indicates that there was no significant difference in the weight distribution between the two groups when perturbing the different sensory systems and comparing the right and left foot, individually. Therefore, the Non-PN cDMII group did not use a medial-lateral weight strategy for weight distribution in the different tasks, alternatively, they used an anterior and posterior strategy to maintain their balance. Our results concur with previous studies in which, to our understanding, a difference in plantar pressure in the population with controlled diabetes has yet to be found (Lafound et al., 2004 & Syed et al., 2013). In their study, Syed and colleagues (2013) reflected that there was no difference in pressure of the different zones of the foot in participants with DM without neuropathy and participants without DM. This study did not alter any sensory system and integrated the visual, proprioceptive, and vestibular systems in their tasks.

Furthermore, Ahmmed et al., (2003) studied three groups, participants with DM with neuropathy, participants with DM without neuropathy and the control group, and they, too, did not find a significant difference in weight distribution between both lower extremities when performing two balance tasks (EO, EC). Contrary to the authors, our study ventures further and observes weight distribution in conditions that compromised the visual, proprioceptive and vestibular systems (Lafound et al., 2004 & Syed et al., 2013). For consideration in future research, performing a study where weight distribution between rear-foot and forefoot in each foot individually is evaluated would be beneficial as, in this study, it was demonstrated that participants with DMII sway more anteriorly and posteriorly compared to medially and laterally.

Our results suggest that when two systems were perturbed concurrently, there was a greater instability present in subjects with Non-PN cDMII, thus depicting deficits in using only one system to maintain static standing balance. Participants with Non-PN cDMII demonstrated the greatest instability in tasks where the vestibular and/or proprioceptive systems were perturbed, which suggests the first changes and/or deficits can be observed in these two systems. Perhaps one way to target these instabilities is by using the Grewal et al., 2015 idea of a “diabetic-specific, tailored, sensor-based exercise training” to address their postural balance issues.

CONCLUSION

The purpose of the study was to identify which postural strategies were utilized during static standing balance among individuals with controlled DMII without neuropathy. Our results revealed that in the tasks where the vestibular and/or proprioceptive systems were perturbed, the group with DMII presented a higher displacement of the CoP in comparison to the control group. Furthermore, these results revealed that participants with DMII rely on their vision as a strategy to maintain their static postural control, however, this is a deficient strategy. Similarly, the proprioceptive system seems to be most affected.

This research shows new information about the deficiencies and strategies that were found in individuals with controlled DMII without neuropathy. As clinicians working with people with diabetes, this study presents a clinical advancement in which we can create programs focused on strategies that aid the proprioceptive and vestibular systems in individuals with DMII to help decrease fall risks, which affect the population with this condition early on.

Future research is necessary to evaluate this population over a long-term period to identify if the strategies observed in this study will influence the tendency of falling. Though this study took into consideration other studies' number of participants (Mueller et al., 1994; Petrofsky J et al., 2005; Dingwell JB, et al., 2000; Toosizadeh N et al., 2015), our recommendation would be to take a larger sample (n) size. Additionally, as part of the inclusion criteria, evaluation of muscle mass should be considered using plicometry, as BMI only takes body fat percentage into consideration. Finally, it would be immensely useful to evaluate the velocity of change of the CoP, due to the lack of CoP variables. The literature indicates that if the velocity is high enough, it will require the individual to utilize the stepping strategy to regain his/her balance as a result of their centre of mass moving outside of the base of support.

ACKNOWLEDGMENTS

Thank you to the School of Health Professionals of the University of Puerto Rico, Medical Sciences Campus for supporting the researchers in allowing them the use of the Biomechanics Laboratory.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Agrawal, Y., Carey, J., Della, C., Schubert, M., Minor, L. Diabetes, vestibular dysfunction, and falls: Analyses from the National Health and Nutrition Examination Survey. Otol Neurotol. 2010;31(9);1445-1450. https://doi.org/10.1097/mao.0b013e3181f2f035

Ahmmed, A., Mackenzie, I. Posture changes in diabetes mellitus. The Journal of Laryngology & Otology. May, 2003;117:358-364. https://doi.org/10.1258/002221503321626393

Azidah, A.K., Hasniza, H., Zunaina, E. Prevalence of Falls and Its Associated Factors among Elderly Diabetes in A Tertiary Center, Malaysia. Curr Geriontol Geriatr Res. 2012:1-5. https://doi.org/10.1155/2012/539073

Balady, G.J., Chaitman, B., Driscoll, D., Foster, C., Froelicher, E., Gordon, N., Pate, R., Rippe, J., Bazzarre, T. Recommendations for cardiovascular screening, staffing, and emergency policies at health/fitness facilities. Circulation. 1998 Jun 9;97(22):2283-93. https://doi.org/10.1161/01.cir.97.22.2283

Bell-Krotoski, J., Weinstein, S., Weinstein, C. Testing sensibility, including touch-pressure, two-point discrimination, point localization, and vibration. J Hand Ther. April-June 1993;6(2):114-23. https://doi.org/10.1016/s0894-1130(12)80292-4

Berg K., Wood-Dauphinee, S., Williams, J.I. The Balance Scale: Reliability Assessment with Elderly Residents and Patients with an Acute Stroke. Scand J Rehab Med. 1995;27(1):27-36.

Bohannon, R. W., Larkin, P. A., et al. Decrease in timed balance test scores with aging. Physical Therapy. 1984;64(7):1067-1070. https://doi.org/10.1093/ptj/64.7.1067

Bonnet, C., Ray, C. Peripheral neuropathy may be not the only fundamental reason explaining increased sway in diabetic individuals. Clin Biomech.2011;26;699-706. https://doi.org/10.1016/j.clinbiomech.2011.03.004

Brenton-Rule, A., Mattock, J., Carroll, M., et al. Reliability of the TekScan MatScan® system for the measurement of postural stability in older people with rheumatoid arthritis. J Foot Ankle Res.2012; 5: 21. https://doi.org/10.1186/1757-1146-5-21

Center for Disease Control and Prevention. New CDC report: More than 100 million Americans have diabetes or prediabetes. Published: July 18, 2017 https://www.cdc.gov/media/releases/2017/p0718-diabetes-report.html

Dingwell, J.B., Cusmano, J.P., Sternad, D., Cavanagh, P.R. Slower speeds in patients with diabetic neuropathy lead to improved local dynamic stability of continuous overground walking. J Biomech. 2000; 33:1269-1277. https://doi.org/10.1016/s0021-9290(00)00092-0

Duncan, P. W., Weiner, D. K., et al. Functional reach: a new clinical measure of balance. J Gerontol. 1990;45(6):M192-197.

Grewal, G.S., Schwenk, M., Lee-Eng, J.Parvaneh, S., Bharara, M., Menzies, R.A., Talal, T.K., Armstrong, D.G., Najafi B. Sensor-Based Interactive Balance Training with Visual Joint Movement Feedback for Improving Postural Stability in Diabetics with Peripheral Neuropathy: A Randomized Controlled Trial. Gerontology. 2015;61:567-574. https://doi.org/10.1159/000371846

Kisner, C., Colby, L. Therapeutic Exercise: Foundations and Techniques.Philadelphia, PA: F.A.Davis; 2012.

Lafond, D., Corriveau, H., Prince, F. Postural control mechanisms during quiet standing in patients with diebetic sensory neuropathy. Diabetes Care.Jan 2004;27(1):173-178. https://doi.org/10.2337/diacare.27.1.173

Low, D.C., Walsh, G.S., & Arkesteijn, M. Sports Med (2017) 47: 101. Effectiveness of Exercise Interventions to Improve Postural Control in Older Adults: A Systematic Review and Meta-Analyses of Centre of Pressure Measurements. Sports Med. 2017 Jan;47(1):101-112. https://doi.org/10.1007/s40279-016-0559-0

Maurer, M.S., Burcham, J., Cheng, H. Diabetes Mellitus Is Associated With an Increased Risk of Falls in Elderly Residents of a Long-Term Care Facility. J Ger Med Sci.2005; 60A(9): 1157-62. https://doi.org/10.1093/gerona/60.9.1157

Mueller, M.J., Minor, S.D., Sahrmann, S.A., Schaaf, J.A., Strube, M.J. Differences in the gait characteristics of patients with diabetes and peripheral neuropathy compared with age-matched controls. Phys Ther. 1994 Apr;74(4):299-308. https://doi.org/10.1093/ptj/74.4.299

Oppenheim, U., Kohen-Raz, R., Alex, D., et al. Postural Characteristic of Diabetic Neuropathy. Diabetes Care.1992;22:328-332. https://doi.org/10.2337/diacare.22.2.328

Palma, F.H., Antigual, D.U., Martínez, S.F., Monrroy, M.A., Gajardo, R.E. Static balance in patients presenting diabetes mellitus type 2 with and without diabetic polyneuropathy. Arq Bras Endocrinol Metabol. 2013 Dec;57(9):722-6. https://doi.org/10.1590/s0004-27302013000900008

Petrofsky, J., Lee, S., Bweir, S. Gait characteristics in people with type 2 diabetes mellitus. Eur J Appl Physiol. 2005 Mar;93(5-6):640-7. https://doi.org/10.1007/s00421-004-1246-7

Simoneau, G., Ulbrecht, J., Derr, J., Cavanagh, P. Role of somatosensory input in the control of human posture. Gait and Posture. 1995;3:115-122. https://doi.org/10.1016/0966-6362(95)99061-o

Rosario, M.G., Collazo, H., Mateo, M., et al. Increased static postural sway after energy drink consumption: A randomized trial [version 1; referees: 2 approved with reservations]. F1000Research 2017, 6:2036. https://doi.org/10.12688/f1000research.12565.1

Rosario, M.G., Orozco, E., Babilonia, N., et al. Evaluation of controlled type II diabetics ascending and descending a ramp surface at an imposed speed: A case-control study [version 1; referees: awaiting peer review]. F1000Research 2018, 7:408. https://doi.org/10.12688/f1000research.14401.1

Rosario, M.G., López, L., Méndez, M., et al. Proprioception and vestibular alterations affect postural control in children with mild autism: A pilot study [version 1; referees: awaiting peer review]. F1000Research 2018, 7:305. https://doi.org/10.12688/f1000research.14179.1

Syed, N., Maiya, A., Hanifa, N., Goud, S. Plantar pressure in diabetes with no know neuropathy. J Diabetes.2013;5(3):302-8.

Thapa, P., Gideon, P., Brockman, K., Fought, R., Ray, W. Clinical and biomechanical Measures of balances as fall predictors in ambulatory nursing home residents. The Journals of Gerontology.1996;51A(5):M239-M246. https://doi.org/10.1093/gerona/51a.5.m239

Toosizadeh, N., Mohler, J., Armstrong, D.G., Talal, T.K., Najafi, B. The influence of diabetic peripheral neuropathy on local postural muscle and central sensory feedback balance control. PLoS One. 2015 Aug 10;10(8):e0135255. https://doi.org/10.1371/journal.pone.0135255

Vision Problems in the U.S. Prevalence of Adults Vision Impairment and Age-Related Eye Disease in America. http://www.visionproblemsus.org/diabetic-retinopathy/diabetic-retinopathy-map.html Published: 2012. Accessed: March 24, 2018.

Wallace, C., Reiber, G. E., LeMaster, J., Smith, D.G., Sullivan, K., Hayes, S., Vath, C. Incidence of falls, risk factors for falls, and fall-related fractures in individuals with diabetes and a prior foot ulcer. Diabetes Care. 2002 Nov;25(11):1983-6. https://doi.org/10.2337/diacare.25.11.1983

Whiney, S.L., Wrisley, D.M., Marchetti, G.F., Gee, M.A., Redfern, M.S., Furman, J.M. Clinical Measurement of Sit-to-Stand Performnce in People With Balance Disorders: Validity of Data for the Five-Times-Sit-to-Stand Test. PHYS THER. 2005;85:1034-1045. https://doi.org/10.1093/ptj/85.10.1034