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Test-Retest Reliability of Kinematic Parameters of Timed Up and Go in People with Type 2 Diabetes

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Abstract: Diabetes mellitus is a chronic disease defined as a state of hyperglycaemia in fasting or postprandial states. Patients with type 2 diabetes mellitus (T2DM) often show reduced physical function, including low levels of strength, balance or mobility. In this regard, the timed up and go (TUG) is a widely used physical fitness test in people with T2DM. However, there is a lack of studies evaluating the properties TUG in this population. The present study aimed to evaluate the test-retest reliability of kinetic and kinematic parameters obtained from TUG in the diabetic population with different levels of diabetic neuropathy. A total of 56 patients with T2DM participated in the study. They were divided into three groups according to the vibration threshold: (a) severe neuropathy, (b) moderate neuropathy and (c) normal perception. The TUG was performed using two force platforms to assess kinematic measurements. The results show that both kinetic and kinematic variables had good to excellent reliability. The reliability of TUG was excellent for the whole sample and the groups with non-severe neuropathy. However, it was just good for the group with severe neuropathy.

Keywords: forefoot; Gait; Heel; TUG; Type 2 diabetes mellitus

1. Introduction

Diabetes mellitus (DM) is a chronic disease defined as a state of hyperglycaemia in fasting or postprandial states [1]. DM is one of the largest global public health problems and affects approximately 415 million people in the world among adults aged 20–79 years-old. It is estimated that, in the year 2040, there will be 642 million persons (confidence interval 521–829 million) with DM in the world [2]. The International Diabetes Federation also estimates that, globally, 46.5% of people suffering from diabetes were still undiagnosed in 2015, which may markedly increase the reported prevalence. According with the American Diabetes Association (ADA), the total costs for diabetes care in the United States were approximately 245 billion dollars due to medical costs, lost productivity and disability [3]. Much of the burden of this disease comes from vascular complications, which include cardiovascular disease, retinopathy and nephropathy. Another complication is diabetic peripheral neuropathy, affecting more than 50% of long-term diabetic cases [4].

Diabetic neuropathy is characterised by progressive degeneration that primarily affects small-diameter cutaneous nociceptive fibres [5]. It may also affect motor fibres, which can cause muscular weakness. In this regard, persons with DM have a reduction of 17% and 14% in the strength of the flexor and extensor muscles of the knee, respectively [6]. Somatosensory feedback is a relevant factor to maintain balance and there is strong evidence showing that diabetic neuropathy affects this source of information, leading to alterations in postural and gait performance [7]. In this regard, previous studies have demonstrated that the main sources of deterioration in the balance in persons with type 2 DM (T2DM) are deficits in the proprioception of the foot and the ankle [8], or a loss of sensitivity in the feet [9].

The neurologic exam of the lower limb is the most important aspect in the clinical diagnosis of diabetic neuropathy [10]. The loss of foot vibration perception is associated with an increased risk of foot ulceration in people with diabetes [11]. In this regard, Abbott et al. [12] showed that each one-unit increment in the foot vibration threshold increases the risk of foot ulceration by more than 5% in a single year period. Therefore, the foot vibration threshold is a very relevant variable in the diabetic population.

Previous studies have demonstrated a relationship between the foot vibration threshold and the risk of falling [13], gait speed [14] and mobility disability [15]. Although balance and mobility tests are of great interest in DM studies due to the association with the risk of falling and the ability to perform activities of daily living, a recent systematic review showed that there is a lack of studies evaluating the properties of these tests when they are conducted in the diabetic population [16].

Therefore, the main objective of this study was to evaluate the test-retest reliability of the kinetic and kinematic parameters obtained from one of the most widely used tests for assessing balance and mobility, the timed up and go (TUG), in people suffering from T2DM. The second objective was to calculate the reliability of TUG according to the severity of peripheral neuropathy (assessed through an evaluation of the foot vibration threshold).

2. Materials and Methods

2.1. Participants

A total of 56 patients with DM participated in the study. Of these, 40 were men and 16 were women. The following inclusion criteria were: (a) diagnosed with T2DM, (b) affected by at least one risk factor of diabetic neuropathy: (1) being overweight, (2) a former smoker, (3) diagnosed with diabetic nephropathy and (4) diagnosed with diabetic retinopathy, (c) levels of glycated haemoglobin higher than 5.7%, and (d) have read and signed the written informed consent. In addition to these inclusion criteria, some exclusion criteria were defined: (a) pregnancy, (b) the use of psychotropic or chemotherapeutic medications, (c) affected by other diseases that may influence balance and gait, such as Parkinson's disease, and (d) patients with a high risk of non-diabetic neuropathy (HIV or uraemia). The protocol of the present study was approved by the Committee of Bioethics of the University and was developed in accordance with the updated Helsinki Declaration and the national legislation on bioethics, biomedical research and personal data confidentiality.

2.2. Procedure

After reading and signing the written informed consent, participants were measured and weighed. They were also asked about their age and years since diagnosis. Then, the vibration threshold was evaluated and, finally, the TUG was conducted after a light warm-up.

The foot vibration threshold was assessed using a Biothensiometer Vibratron II (Physitemp Instruments, Inc. Clifton; New Jersey; USA). This device drives vibration to modules A and B placed under the feet of the participant. Each module has a vibrating pole on the top, which vibrates at a frequency of 120 Hz. Therefore, the vibration threshold is determined by modifying the amplitude. These vibration units are related to the amplitude of the movement in microns according to the formula:

$A = x^2/2$ (where x is the vibration units (vu) and A is the amplitude in microns (μm)). The present study used the protocol the 'force two alternative choices procedure', which is one of the two methods suggested by the manufacturer. Participants were asked to place their first toe on the vibrating pole. The procedure started when the participant felt the vibration in the left or right toe. After that, the amplitude was reduced progressively until the participant was not able to tell which pole was vibrating. When the participant failed to detect vibration, the amplitude of the vibration was increased. The vibration threshold was then calculated using the last five rights and wrongs, but omitting the extreme low and high values. The average of the remaining eight values was then computed to calculate the vibration threshold [17].

TUG was performed three times, with a 5-min rest in between. The first repetition was for familiarisation, the second was the test measure and the third was the retest measure. All participants performed a light warm-up which included walking and joint mobility for 5 min. In the TUG, two force platforms (Kistler, NY, USA) were placed between the chair and the mark where participants had to turn around. Therefore, participants stepped on the platforms before and after reaching the mark placed at 3 m. The time required to complete the full test was assessed manually with a stopwatch by an expert rater.

Variables obtained from the force platforms included the duration of (a) the double support phase (both feet on the platforms), (b) left support (only the left foot on the platforms) and (c) right support (only the right foot on the platforms), as well as the left and right peak forces from the forefoot and the heel.

The results are presented for the whole sample (n = 56), and also according to the degree of neuropathy based on vibration perception, i.e., severe neuropathy (n = 22), moderate neuropathy (n = 22) and normal perception (n = 12). To classify patients into one of the three groups, the cut-off points suggested by normative values of the manual of the measuring device were considered.

2.3. Statistical Analysis

Descriptive statistics included mean and standard deviation (SD) of age, weight, glycated haemoglobin, years since T2DM diagnosis, body mass index and vibration threshold were calculated for the whole sample and divided into women or men. Parametric and non-parametric tests were conducted based on the results of Shapiro-Wilk and Kolmogorov-Smirnov tests.

Differences between test and retest were evaluated using the paired samples t-test or Wilcoxon signed rank test when appropriate. The time spent to complete the TUG, the duration of phases and the forces registered by the force platforms were included in those analyses to compare the test and retest results.

Reliability analyses were conducted in accordance with the recommendations of Weir [18]. An intraclass correlation coefficient (ICC) of 3.1 (two-way mixed, single measures) with a 95% CI for test and retest [19] was selected. Both absolute and relative reliability were computed. The standard error of measurement (SEM) was calculated as $SEM = SD\sqrt{1 - ICC}$ where SD is the mean SD of the three repetitions, while the smallest real difference (SRD) was $SRD = 1.96 \times SEM \times \sqrt{2}$. These measures were converted into percentages (%SEM and %SRD, respectively) to enable comparisons with other investigations.

3. Results

3.1. Participant Characteristics

Table 1 summarises the participant characteristics. A total of 40 men and 16 women aged 64.52 (8.41) and 67.43 (8.86), respectively, participated in the present study. The mean weight of the whole sample was 80.08 (17.59) kg and the body mass index (BMI) was 28.81 (4.40) kg/m^2. The mean vibration threshold was 4.27 (1.90) for women and 5.75 (2.50) for men.

Table 1. Participant characteristics.

	All Participants (n = 56)	Men (n = 40)	Women (n = 16)
Age (years)	65.35 (8.56)	64.52 (8.41)	67.43 (8.86)
Weight (kg)	80.08 (17.59)	85.26 (18.03)	67.11 (6.14)
Glycated haemoglobin (%)	6.66 (0.91)	6.67 (0.90)	6.63 (0.94)
Years since diagnosis	9.10 (7.43)	9.07 (6.52)	9.18 (9.59)
BMI (kg/m^2)	28.81 (4.40)	29.24 (4.84)	27.73 (2.85
Vibration threshold (vu)	5.33 (2.42)	5.75 (2.50)	4.27 (1.90)

BMI: body mass index; vu: vibration units.

3.2. Kinematic Variables of the Timed Up and Go

Table 2 summarises the mean duration of the walking phases in the TUG. The results from the paired samples *t*-test or Wilcoxon signed rank test showed that there were significant differences between the test and retest values in some of the variables, including the time required to complete the TUG and the duration of the left support before reaching the mark for the whole sample. These differences were also observed in the group with severe neuropathy.

Table 2. Differences between test and retest on the duration of the walking phases in the entire sample and in participants with (a) severe neuropathy, (b) moderate neuropathy and (c) normal perception.

	Test Measurement	Test	Retest	*p*-Value [a]
GENERAL (n = 56)	TUG (S)	8.10 (1.37)	7.80 (1.28)	<0.001
	Double support phase duration (before reaching the mark)	0.09 (0.02)	0.09 (0.02)	0.341 [a]
	Double support phase duration (after reaching the mark)	0.10 (0.02)	0.10 (0.02)	0.483 [a]
	Right support duration (before reaching the mark)	0.62 (0.09)	0.60 (0.09)	0.047 [a]
	Left support duration (before reaching the mark)	0.62 (0.09)	0.60 (0.08)	0.005 [a]
	Right support duration (after reaching the mark)	0.62 (0.08)	0.61 (0.08)	0.261
	Left support duration (after reaching the mark)	0.63 (0.09)	0.63 (0.10)	0.399 [a]
SEVERE (n = 22)	TUG (S)	8.36 (1.40)	7.94 (1.10)	0.007
	Double support phase duration (before reaching the mark)	0.09 (0.02)	0.09 (0.02)	0.463 [a]
	Double support phase duration (after reaching the mark)	0.10 (0.02)	0.10 (0.02)	0.637 [a]
	Right support duration (before reaching the mark)	0.62 (0.09)	0.60 (0.08)	0.117 [a]
	Left support duration (before reaching the mark)	0.63 (0.08)	0.60 (0.06)	0.020 [a]
	Right support duration (after reaching the mark)	0.62 (0.06)	0.62 (0.06)	0.610
	Left support duration (after reaching the mark)	0.62 (0.06)	0.63 (0.08)	0.986 [a]
MODERATE (n = 22)	TUG (S)	7.92 (1.47)	7.69 (1.54)	0.016
	Double support phase duration (before reaching the mark)	0.09 (0.03)	0.09 (0.02)	0.930 [a]
	Double support phase duration (after reaching the mark)	0.10 (0.02)	0.10 (0.03)	0.974 [a]
	Right support duration (before reaching the mark)	0.61 (0.10)	0.60 (0.11)	0.443 [a]
	Left support duration (before reaching the mark)	0.60 (0.11)	0.60 (0.11)	0.750 [a]
	Right support duration (after reaching the mark)	0.61 (0.10)	0.61 (0.10)	0.697
	Left support duration (after reaching the mark)	0.64 (0.12)	0.64 (0.12)	0.650 [a]
NORMAL (n = 12)	TUG (S)	7.94 (1.16)	7.74 (1.15)	0.095
	Double support phase duration (before reaching the mark)	0.09 (0.01)	0.08 (0.01)	0.260 [a]
	Double support phase duration (after reaching the mark)	0.10 (0.01)	0.09 (0.02)	0.164 [a]
	Right support duration (before reaching the mark)	0.63 (0.09)	0.61 (0.07)	0.153 [a]
	Left support duration (before reaching the mark)	0.62 (0.06)	0.59 (0.06)	0.025 [a]
	Right support duration (after reaching the mark)	0.61 (0.05)	0.60 (0.06)	0.235
	Left support duration (after reaching the mark)	0.63 (0.08)	0.62 (0.09)	0.312 [a]

[a] *p*-values obtained from the Wilcoxon signed rank test.

Reliability parameters for the total time required to complete the TUG and duration of phases can be observed in Table 3. The ICC was good (0.70 to 0.90) or excellent (>0.90) for almost every variable and group. The best reliability was obtained for the time required to complete the TUG, which was excellent in the two groups with non-severe neuropathy, while it was just good in the group with severe neuropathy.

Table 3. Test-retest analyses of the duration of the walking phases in the entire sample and in participants with (a) severe neuropathy, (b) moderate neuropathy and (c) normal perception.

	Test Measurement	ICC (95% CI)	SEM (s)	SEM (%)	SRD (s)	SRD (%)
GENERAL (n = 56)	TUG (S)	0.927 (0.878–0.956)	0.36	4.52	0.99	12.55
	Double support phase duration (going)	0.760 (0.623–0.852)	0.01	14.07	0.03	39.02
	Double support phase duration (return)	0.801 (0.683–0.878)	0.01	10.73	0.03	29.74
	Right support duration (before reaching the mark)	0.865 (0.781–0.919)	0.03	5.74	0.09	15.93
	Left support duration (before reaching the mark)	0.845 (0.749–0.906)	0.03	5.80	0.09	16.08
	Right support duration (after reaching the mark)	0.876 (0.798–0.925)	0.02	4.71	0.08	13.05
	Left support duration (after reaching the mark)	0.860 (0.772–0.915)	0.03	5.77	0.10	16.01
SEVERE (n= 22)	TUG (S)	0.870 (0.714–0.944)	0.45	5.54	1.25	15.37
	Double support phase duration (going)	0.855 (0.684–0.937)	0.01	10.75	0.02	29.81
	Double support phase duration (return)	0.853 (0.678–0.936)	0.01	7.60	0.02	21.07
	Right support duration (before reaching the mark)	0.782 (0.544–0.903)	0.04	6.58	0.11	18.25
	Left support duration (before reaching the mark)	0.730 (0.454–0.879)	0.04	6.63	0.11	18.38
	Right support duration (after reaching the mark)	0.853 (0.678–0.936)	0.02	4.07	0.07	11.30
	Left support duration (after reaching the mark)	0.727 (0.448–0.877)	0.03	6.01	0.10	16.66
MODERATE (n = 22)	TUG (S)	0.963 (914–0.985)	0.29	3.727	0.80	10.31
	Double support phase duration (going)	0.723 (0.441–0.875)	0.01	18.06	0.04	50.07
	Double support phase duration (return)	0.861 (0.695–0.940)	0.01	10.83	0.03	30.03
	Right support duration (before reaching the mark)	0.914 (0.805–0.964)	0.03	5.37	0.09	14.90
	Left support duration (before reaching the mark)	0.923 (0.824–0.967)	0.03	5.11	0.08	14.17
	Right support duration (after reaching the mark)	0.903 (0.781–0.959)	0.03	5.43	0.09	15.06
	Left support duration (after reaching the mark)	0.912 (0.800–0.962)	0.03	5.71	0.10	15.83
NORMAL (n = 12)	TUG (S)	0.938 (0.800–0.982)	0.28	3.67	0.79	10.17
	Double support phase duration (going)	0.565 (0.018–0.852)	0.01	11.93	0.02	33.08
	Double support phase duration (return)	0.511 (0.059–0.829)	0.01	15.04	0.04	41.69
	Right support duration (before reaching the mark)	0.880 (0.636–0.964)	0.03	4.82	0.08	13.38
	Left support duration (before reaching the mark)	0.881 (0.639–0.964)	0.02	3.70	0.06	10.25
	Right support duration (after reaching the mark)	0.774 (0.387–0.929)	0.02	4.64	0.07	12.88
	Left support duration (after reaching the mark)	0.843 (0.543–0.952)	0.03	5.68	0.09	15.76

3.3. Peak Forces from the Heel and the Forefoot in the Timed Up and Go

Regarding the peak forces from the heel and the forefoot, differences between test and retest were only observed for the right heel and left forefoot forces in the group without neuropathy. For the rest of the variables, the retest was not significantly different than the test (see Table 4).

Table 4. Differences between the test and retest on the peak forces from the heel and the forefoot forces in the entire sample and in participants with (a) severe neuropathy, (b) moderate neuropathy and (c) normal perception.

	Test Measurement in Newtons	Test	Retest	p-Value
GENERAL (n = 56)	Right forefoot forces (before reaching the mark)	846.91 (185.68)	841.62 (192.78)	0.525 [a]
	Left forefoot forces (before reaching the mark)	827.33 (195.94)	828.06 (187.55)	0.562 [a]
	Right forefoot forces (after reaching the mark)	823.69 (181.65)	819.28 (174.34)	0.707 [a]
	Left forefoot forces (after reaching the mark)	773.50 (179.97)	767.44 (179.11)	0.458 [a]
	Right heel forces (before reaching the mark)	881.64 (201.23)	902.94 (209.41)	0.058 [a]
	Left heel forces (before reaching the mark)	934.64 (217.76)	944.97 (217.63)	0.098 [a]
	Right heel forces (after reaching the mark)	938.52 (226.32)	940.87 (211.95)	0.579 [a]
	Left heel forces (after reaching the mark)	937.35 (210.51)	943.70 (214.06)	0.458 [a]
SEVERE (n= 22)	Right forefoot forces (before reaching the mark)	868.77 (198.23)	867.59 (215.78)	0.833 [a]
	Left forefoot forces (before reaching the mark)	879.37 (208.31)	857.73 (204.77)	0.291 [a]
	Right forefoot forces (after reaching the mark)	855.99 (204.95)	849.56 (204.22)	0.615 [a]
	Left forefoot forces (after reaching the mark)	821.39 (199.56)	820.55 (194.15)	0.783 [a]
	Right heel forces (before reaching the mark)	937.91 (209.96)	958.33 (237.64)	0.485 [a]
	Left heel forces (before reaching the mark)	994.51 (229.16)	1004.19 (232.83)	0.338 [a]
	Right heel forces (after reaching the mark)	991.13 (263.60)	973.35 (237.58)	0.548 [a]
	Left heel forces (after reaching the mark)	983.31 (226.01)	979.73 (219.78)	0.783 [a]

Table 4. *Cont.*

	Test Measurement in Newtons	Test	Retest	*p*-Value
MODERATE (n = 22)	Right forefoot forces (before reaching the mark)	846.14 (212.30)	827.06 (207.90)	0.178 [a]
	Left forefoot forces (before reaching the mark)	809.70 (215.55)	819.77 (205.52)	0.638 [a]
	Right forefoot forces (after reaching the mark)	820.03 (187.24)	809.08 (174.89)	0.527 [a]
	Left forefoot forces (after reaching the mark)	747.40 (193.17)	741.54 (185.78)	0.200 [a]
	Right heel forces (before reaching the mark)	860.34 (204.46)	877.55 (202.41)	0.408 [a]
	Left heel forces (before reaching the mark)	919.46 (221.58)	934.12 (221.63)	0.168 [a]
	Right heel forces (after reaching the mark)	935.64 (208.33)	938.26 (211.80)	0.961 [a]
	Left heel forces (after reaching the mark)	929.66 (206.01)	947.18 (225.00)	0.200 [a]
NORMAL (n = 12)	Right forefoot forces (before reaching the mark)	808.24 (93.51)	820.69 (110.33)	0.136 [a]
	Left forefoot forces (before reaching the mark)	764.25 (100.23)	788.90 (107.78)	0.006 [a]
	Right forefoot forces (after reaching the mark)	771.20 (112.84)	782.47 (102.16)	0.388 [a]
	Left forefoot forces (after reaching the mark)	733.56 (83.56)	717.58 (113.36)	0.754 [a]
	Right heel forces (before reaching the mark)	817.53 (163.63)	847.94 (150.04)	0.099 [a]
	Left heel forces (before reaching the mark)	852.69 (167.82)	856.27 (153.98)	0.695 [a]
	Right heel forces (after reaching the mark)	847.34 (161.18)	886.09 (160.69)	0.034 [a]
	Left heel forces (after reaching the mark)	867.18 (182.55)	871.26 (178.58)	0.754 [a]

[a] *p*-values obtained from the Wilcoxon signed rank test.

Table 5 summarises the reliability analyses of the kinetic variables for the whole sample and according to the neuropathy classification. Reliability was excellent (ICC > 0.90) in almost every variable and group, except for the left forefoot forces after reaching the mark in the group with normal vibration perception.

Table 5. Test-retest analyses on the peak forces from the heel and the forefoot forces in the entire sample and in participants with (a) severe neuropathy, (b) moderate neuropathy and (c) normal perception.

	Test Measurement in Newtons	ICC (95% CI)	SEM (N)	SEM (%)	SRD (N)	SRD (%)
GENERAL (n = 56)	Right forefoot forces (before reaching the mark)	0.937 (0.894–0.962)	47.49	5.62	131.65	15.59
	Left forefoot forces (before reaching the mark)	0.944 (0.906–0.967)	45.37	5.48	125.77	15.19
	Right forefoot forces (after reaching the mark)	0.955 (0.925–0.974)	37.75	4.59	104.66	12.74
	Left forefoot forces (after reaching the mark)	0.942 (0.903–0.966)	43.23	5.61	119.85	15.55
	Right heel forces (before reaching the mark)	0.946 (0.910–0.968)	47.71	5.34	132.25	14.82
	Left heel forces (before reaching the mark)	0.941 (0.901–0.965)	52.87	5.62	146.57	15.59
	Right heel forces (after reaching the mark)	0.935 (0.892–0.961)	55.86	5.94	154.86	16.48
	Left heel forces (after reaching the mark)	0.955 (0.925–0.974)	45.03	4.78	124.82	13.27
SEVERE (n= 22)	Right forefoot forces (before reaching the mark)	0.952 (0.888–0.980)	45.35	5.22	125.71	14.48
	Left forefoot forces (before reaching the mark)	0.937 (0.854–0.973)	51.84	5.96	143.69	16.54
	Right forefoot forces (after reaching the mark)	0.968 (0.925–0.987)	36.59	4.29	101.44	11.89
	Left forefoot forces (after reaching the mark)	0.973 (0.936–0.989)	32.34	3.94	89.66	10.92
	Right heel forces (before reaching the mark)	0.947 (0.878–0.978)	51.52	5.43	142.81	15.06
	Left heel forces (before reaching the mark)	0.959 (0.903–0.983)	46.77	4.68	129.64	12.97
	Right heel forces (after reaching the mark)	0.933 (0.846–0.972)	64.86	6.60	179.79	18.30
	Left heel forces (after reaching the mark)	0.959 (0.904–0.983)	45.13	4.59	125.10	12.74
MODERATE- (n = 22)	Right forefoot forces (before reaching the mark)	0.925 (0.828–0.968)	57.53	6.87	159.49	19.06
	Left forefoot forces (before reaching the mark)	0.953 (0.890–0.980)	45.64	5.60	126.51	15.52
	Right forefoot forces (after reaching the mark)	0.944 (0.871–0.976)	42.84	5.26	118.77	14.58
	Left forefoot forces (after reaching the mark)	0.939 (0.858–0.974)	46.79	6.28	129.71	17.42
	Right heel forces (before reaching the mark)	0.947 (0.878–0.978)	46.83	5.38	129.81	14.93
	Left heel forces (before reaching the mark)	0.913 (0.803–0.963)	65.36	7.05	181.18	19.54
	Right heel forces (after reaching the mark)	0.945 (0.873–0.977)	49.26	5.25	136.55	14.57
	Left heel forces (after reaching the mark)	0.960 (0.906–0.983)	43.10	4.59	119.47	12.73
NORMAL (n = 12)	Right forefoot forces (before reaching the mark)	0.931 (0.778–0.980)	26.77	3.28	74.20	9.11
	Left forefoot forces (before reaching the mark)	0.976 (0.920–0.993)	16.11	2.07	44.66	5.75
	Right forefoot forces (after reaching the mark)	0.926 (0.765–0.978)	29.24	3.76	81.06	10.43
	Left forefoot forces (after reaching the mark)	0.697 (0.234–0.902)	54.20	7.47	150.24	20.70
	Right heel forces (before reaching the mark)	0.915 (0.732–0.975)	45.72	5.49	126.74	15.22
	Left heel forces (before reaching the mark)	0.934 (0.789–0.981)	41.33	4.83	114.57	13.40
	Right heel forces (after reaching the mark)	0.931 (0.778–0.980)	42.27	4.87	117.17	13.51
	Left heel forces (after reaching the mark)	0.928 (0.770–0.979)	48.45	5.57	134.30	15.45

4. Discussion

The present study aimed to evaluate the test-retest reliability of kinetic and kinematic parameters obtained from TUG in the diabetic population. The results were analysed according to the severity of

neuropathy. The main finding was that almost each variable achieved good (ICC between 0.70 and 0.90) or excellent (>0.90) reliability considering the classification by Munro et al. [20].

The reliability of TUG seemed to be conditioned by the severity of neuropathy since the ICC was higher than 0.90 (excellent) for participants with moderate neuropathy and patients with normal foot vibration perception, but just good (0.70 to 0.90) for patients with severe neuropathy. Therefore, although the TUG is reliable in T2DM patients, changes in the duration of the phases (single and double support) must be taken with caution since the %SEM may be relatively high in some cases (over 10%). Furthermore, we can observe how the SRD of the required time to complete the TUG was higher in patients with severe neuropathy. These results must be considered by clinicians and researchers in order to interpret their results when using TUG in the T2DM population. This is relevant since a previous study showed that patients with diabetic neuropathy have worse health-related quality of life and lower functional status than patients without diabetic neuropathy [21]. Neuropathy leads to balance impairments [22], gait and mobility alterations [23,24] and an increased risk of falls [25]. In addition, patients with T2DM seem to be more susceptible to falls and consequently to bone fractures [26–28]. Due to the relevance of diabetic neuropathy in patients with T2DM, future studies aimed at improving physical conditioning variables should consider that the smallest clinically relevant improvement may be higher in T2DM patients with this complication.

To our knowledge, this is the first study to assess the reliability of TUG according to the severity of neuropathy. Only one previous study has evaluated the reliability of TUG in the diabetic population [29]. That study was conducted on a sample of 18 older adults with T2DM, and no classification of the participants was performed. Furthermore, that study only evaluated the time needed to complete the TUG and not any other measure such as the duration of walking phases or kinetic parameters. Comparing results from the present study with those obtained by Alfonso-Rosa, Del Pozo-Cruz, Del Pozo-Cruz, Sanudo and Rogers [29], both studies report excellent reliability. However, the ICC and %SEM from that study were 0.98 and 3.5%, respectively, whereas the present study reports an ICC of 0.927 and a %SEM of 4.52. Therefore, the reliability is slightly lower in this study, which may be linked to the greater heterogeneity of the sample in the current study. In this regard, it must be noted that the study by Alfonso-Rosa, Del Pozo-Cruz, Del Pozo-Cruz, Sanudo and Rogers [29] was conducted on 18 older adults with T2DM, while the current one was conducted with 56 adults aged 65.35 (8.56) years.

The current study reported not only the SEM but also the SRD, which is extremely relevant for clinicians and researchers since it indicates whether the differences obtained as a consequence of an intervention program could be considered clinically important [30]. A previous study in T2DM [29] established the SRD for the TUG at 9.8%, whereas in the present study the SRD was 12.55%. This difference could be also explained by the heterogeneity of the sample in the current study. In this regard, the results from the previous study were limited to older adults. Thus, those studies conducted with samples comprised of adults (but not limited older adults) had no information about the reliability and the minimal clinically important difference to interpret their results. Therefore, the current study was needed since it is the first to provide reliability information in a sample comprised of adults (not limited to older adults).

Test-retest analyses have been also reported in kinematic parameters, taking into account the heel and the forefoot forces during the TUG. The results revealed that the reliability of the heel and forefoot forces could be considered as excellent, so future studies can confidently use this as a measurement to evaluate gait patterns in T2DM patients. People with diabetic neuropathy often have balance problems while performing common activities such as walking or ascending/descending stairs [31]. Furthermore, the postural mechanisms at the ankle joints are impaired in diabetic neuropathy patients during quiet standing [32]. Thus, postural instability and gait imbalance in diabetic neuropathy may contribute to a high risk of fall incidence, especially in the geriatric population [7,31]. Therefore, future studies should be focused on the implementation of interventions aimed to modify gait parameters to reduce the risk of falling in T2DM patients. The current study provides useful information in order to interpret

changes achieved after a specific program, stating the minimal clinically relevant change for kinetic and kinematic variables.

The present study has two main limitations. First, although the sample size (n = 56) was sufficient to conduct this test-retest reliability analysis, the group with no alteration in the foot vibration threshold was comprised of only 12 people. The second limitation may be related to the inclusion criteria and the difficulty in determining that peripheral neuropathy is caused by diabetes. Even though the inclusion and exclusion criteria were very restrictive (excluding people with other diseases and people who were taking drugs that may potentially affect balance and gait), there could be other non-diagnosed diseases, environmental factors or healthy/unhealthy habits that may increase or reduce neuropathy. In spite of these two limitations, this study succeeded at reporting reliability parameters according to the severity of neuropathy in patients with T2DM.

5. Conclusions

The reliability of TUG was excellent for the whole sample and the groups with non-severe neuropathy. However, it was just good for the group with severe neuropathy. Regarding the kinetic and kinematic parameters, the reliability was good or excellent for almost every variable and group. The present study reports the minimal change that may be considered real (SRD) and the SEM, which should be considered by future studies aimed to assess the effects of interventions on different variables related to the TUG.

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Abbreviations

ADA	American Diabetes Association
BMI	Body mass index
DM	Diabetes mellitus
ICC	Intraclass correlation coefficient
T2DM	Type 2 diabetes mellitus
TUG	Timed up and go
SEM	Standard error of measurement
SPSS	Statistical Package for Social Sciences
SRD	Smallest real difference

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