Effect of a HIIT protocol on the lower limb muscle power, ankle dorsiflexion and dynamic balance in a sedentary type 1 diabetes mellitus population: a pilot study

Jesús Alarcón-Gómez[1,*], Fernando Martin Rivera[1,2,*], Joaquin Madera[1] and Iván Chulvi-Medrano[1]

[1] Faculty of Physical Activity and Sports, University of Valencia, Valencia, Spain
[2] Research Group in Prevention and Health in Exercise and Sport, University of Valencia, Valencia, Spain
[*] These authors contributed equally to this work.

ABSTRACT

Background: Type 1 diabetes mellitus (T1DM) is commonly associated with premature loss of muscle function, ankle dorsiflexion and dynamic balance. Those impairments, usually, lead to physical functionality deterioration. High-intensity interval training is an efficient and safety methodology since it prevents hypoglycemia and not requires much time, which are the main barriers for this population to practice exercise and increase physical conditioning. We hypothesized that a 6-week HIIT program performed on a cycle ergometer would increase lower limb muscle power, ankle dorsiflexion range of motion and dynamic balance without hypoglycemic situations.
Methods: A total of 19 diagnosed T1DM subjects were randomly assigned to HIIT group (n = 11; 6-week HIIT protocol) or Control group (n = 8; no treatment). Lower limb strength was evaluated through velocity execution in squat with three different overloads. Weight bearing lunge test (WBLT) was performed to test ankle dorsiflexion range of motion and Y-Balance test (YBT) was the test conducted to analyze dynamic balance performance.
Results: Velocity in squat improved a 11.3%, 9.4% and 10.1% ($p < 0.05$) with the 50%, 60% and 70% of their own body mass overload respectively, WBLT performance increased a 10.43% in the right limb and 15.45% in the left limb. YBT showed improvements in all directions (right limb-left limb): Anterior (4.3–6.1%), Posteromedial (1.8–5.2%) and Posterolateral (3.4–4.5%) in HIIT group ($p < 0.05$), unlike control group that did not experience any significant change in any of the variables ($p > 0.05$).
Conclusion: A 6-week HIIT program is safe and effective to improve execution velocity in squat movement, a fundamental skill in daily living activities, as well as ankle dorsiflexion range of motion and dynamic balance to reduce foot ulcers, risk falls and functional impairments. HIIT seems an efficient and safety training methodology not only for overcome T1DM barriers for exercising but also for improving functional capacities in T1DM people.

Submitted 14 May 2020
Accepted 16 November 2020
Published 21 December 2020

Corresponding author
Fernando Martin Rivera,
fernando.martin-rivera@uv.es

Academic editor
Gian Pietro Emerenziani

Additional Information and Declarations can be found on page 12

DOI **10.7717/peerj.10510**

How to cite this article Alarcón-Gómez J, Martin Rivera F, Madera J, Chulvi-Medrano I. 2020. Effect of a HIIT protocol on the lower limb muscle power, ankle dorsiflexion and dynamic balance in a sedentary type 1 diabetes mellitus population: a pilot study. **PeerJ 8:e10510 DOI 10.7717/peerj.10510**

Subjects Anatomy and Physiology, Diabetes and Endocrinology, Kinesiology
Keywords Exercise, High-intensity training, Type 1 diabetes, Physical functionality

INTRODUCTION

Prevalence of Type 1 Diabetes Mellitus (T1DM) is increasing worldwide (*You & Henneberg, 2016*). According to the International Diabetes Federation and World Health Organization, in the world, 25–45 million adults (>20 years old) suffered from T1DM. In reference to children and adolescents (0–20 years old), more than a million live with the disease, with 130.000 new diagnosed cases per year. It was estimated that the number of people with T1DM in the world will increase a 25% by 2030 (*International Diabetes Federation, 2019*; *WHO, 2016*). T1DM is a chronic metabolic disease characterized by the insufficient production of endogenous insulin and it is associated with multiple clinical manifestations that impair health (*Katsarou et al., 2017*). People with T1DM live in a continuous state of elevated glycemia (*Galassetti & Riddell, 2013*). This condition has been demonstrated to compromise skeletal muscle function, even beginning early in life in many cases, what would indicate that muscle dysfunction is a primary diabetic complication (being more accelerated with the development of neuropathy) (*Krause, Riddell & Hawke, 2011*; *Monaco, Gingrich & Hawke, 2019*). Hyperglycemia also promotes the increase in ankle stiffness even without the presence of neuropathy (*Francia et al., 2018*; *Searle et al., 2017*; *Searle, Spink & Chuter, 2018*) and compromises dynamic balance, also in young patients with no complications diagnosed (*Katsarou et al., 2017*; *Kukidome et al., 2017*; *Turcot et al., 2009*), among other physiological complications. Because of that, T1DM causes the premature loss of lower limb strength (*Celes et al., 2017*; *Monaco, Gingrich & Hawke, 2019*), functional capacities such dynamic balance (even in adults <50 years old) (*Camargo et al., 2015*; *D'Silva et al., 2016*; *Kukidome et al., 2017*) and joint mobility in comparison with their healthy counterparts (*Rao et al., 2006*). In T1DM population, low strength is related to functional limitations (*Lopez et al., 2018*; *Papa, Dong & Hassan, 2017*), ankle stiffness has been implicated as a potential factor of overload of the forefoot during the stance phase of the gait due to the reduced dorsiflexion capacity, which result in foot ulcers (*Rao et al., 2006*; *Searle et al., 2017*). Moreover, the increased postural sway caused by the pathology disorders increases the risk of falling (*D'Silva et al., 2016*; *Kukidome et al., 2017*). Thus, these physical consequences of T1DM could end in acute and chronic injuries and physical disability and frailty (*D'Silva et al., 2016*; *Vinik et al., 2017*; *Wu et al., 2020*).

Regular exercise is strongly recommended for people living with type 1 diabetes to prevent mainly comorbidities as the macrovascular (e.g. coronary arterial disease, peripheral arterial disease, and stroke) and microvascular complications (e.g. nephropathy, neuropathy, and retinopathy) of the disease, which lead to physical disability and premature death (*Farinha et al., 2017*; *Scott et al., 2019*). Nonetheless, the majority (>60%) of this population does not complete the general guidelines of exercise proposed by the American College of Sports Medicine (ACSM) and the American Diabetes Association (ADA) (*Leroux et al., 2014*; *Yardley et al., 2014*), which indicate at least 150 min of moderate to vigorous aerobic exercise per week and 2–3 non-consecutive sessions of resistance training with a volume of 8–10 exercises, with 1–3 sets of 10–15 repetitions and an intensity of 50–75% of 1 repetition maximum (RM) (*Farinha et al., 2017*).

The most recurrent pretexts that T1DM people state for not exercising are the lack of time, the fear of a hypoglycemia event and loss of glycemic control due to inadequate knowledge about exercise variables management (*Lascar et al., 2014*). Those reasons make that few people with T1DM benefit from the improvement of aerobic capacity (VO_{2max}), insulin sensitivity, body composition, endothelial function, blood lipid profile, bone density and strength that aerobic and resistance exercises promote (*Codella, Terruzzi & Luzi, 2017*; *Scott et al., 2019*).

The aforementioned barriers that T1DM people face may be overcome with high-intensity interval training (HIIT), a training method that, despite being used since the early 20th century in sport performance, has been discovered to be an interesting tool for those with cardiometabolic diseases in the recent years (*Buchheit & Laursen, 2013*). HIIT involves repeated brief bouts of high intensity (>85% VO_{2max}) interspersed with passive or active recovery periods, requiring lower exercise duration than moderate-intensity continuous training (MICT), also HIIT prevents the drop of glycemia typical of MICT, due to its anaerobic predominance (*Farinha et al., 2017*). There is also evidence to suggest that HIIT elicits at least the same cardiometabolic effects in healthy and pathologic population that MICT does (*De Nardi et al., 2018*; *Hussain, Macaluso & Pearson, 2016*). These safe, effective and time-efficient results are sufficient to consider HIIT as an interesting form of training for the T1DM population. So far, HIIT has been tested in T1DM patients to analyze the long term effects in aerobic capacity and glycemic control (*Boff et al., 2019*; *Farinha et al., 2018*; *Scott et al., 2018*). However, this training strategy has not been investigated as a possible contributor of the development of strength, ankle dorsiflexion and dynamic balance in this population. It is known that HIIT is an interesting tool to improve the lower limb strength in older people (*Herbert et al., 2017*). Moreover, given that the ankle adopts a more dorsiflexed position when increase the intensity during cycling (*Holliday et al., 2019*) and dynamic balance is also enhanced with HIIT performed in cycle ergometer in older people (*Bellumori, Uygur & Knight, 2017*), the aim of this study was to investigate the effects of 6-week high-intensity interval training protocol on lower limb strength, ankle dorsiflexion range of motion and dynamic balance in an inactive T1DM population.

MATERIALS AND METHODS

Participants and research design

We recruited 19 inactive and clinically diagnosed as T1DM (10 males and 9 females) from the Valencian Diabetes Association (VDA) and social media announcement. Baseline characteristics of the sample are presented in Table 1. The following inclusion criteria were adopted: (1) aged 18–45 years, (2) duration of T1DM > 4 years, (3) HbA1C < 10% (4) no structured exercise training programs in the previous 6 months, (5) no known comorbidities not related to diabetes. In an a priori analysis of the required sample size (G*Power V.3.1.9.6), we needed 12 subjects per group, we had 11 participants in the

Table 1 **Lower limbs strength results.**

Mean propulsive velocity	HIIT group (n = 11)		Control group (n = 8)		Size effect
	Pre	Post	Pre	Post	(C.I)
Body mass + 50%	0.79 ± 0.17	0.87 ± 0.21*	0.79 ± 0.14	0.80 ± 0.12	0.42 [−1.49 to 0.65]
Body mass + 60%	0.74 ± 0.16	0.81 ± 0.17*	0.76 ± 0.15	0.75 ± 0.14	0.49 [−1.62 to 0.64]
Body mass + 70%	0.69 ± 0.16	0.76 ± 0.17*	0.73 ± 0.19	0.71 ± 0.15	0.50 [−1.63 to 0.64]

Notes:
* Statistical significance between pre-post within groups $p < 0.05$.
Data are presented in mean ± standard deviation m/s^{-1}.

experimental group and eight in the control group that is why we have titled the article as a pilot study.

Subjects excluded from the study include those who smoke regularly, take any medication that affects heart rate and those who had major surgery planned. Participants were informed of the purposes and risks involved in the study before giving their informed written consent to participate. Furthermore, they completed two questionnaires before the beginning of the measurement protocols: the PAR-Q to assess participants' level of risk to safely participate and the IPAQ (short version), to ensure the previous sedentary behavior of the subjects. The study procedures were in accordance with the principles of the Declaration of Helsinki and were approved by the Institutional Review Board of the University of Valencia which granted its approval to carry out the study within its facilities, IRB code: H1421157445503.

This is a randomized experimental, parallel design, open-label trial. The eligible subjects were randomly allocated (www.randomizer.org) to the experimental (n = 11, 38 ± 5.5 years, 5 men and 6 women, height 1.68 ± 0.09 m, body mass 70.5 ± 7.4 kg and 20.5 ± 8.4 years diagnosed) or control group (n = 8, 35 ± 8.2 years, 4 men and 4 women, height 1.69 ± 0.07 m, body mass 72.05 ± 5.0 kg and 21.1 ± 6.5 years diagnosed), and stratified/classified by gender to ensure a balanced number of men and women in each group. They were instructed not to change their nutritional habits and not to perform any regular exercise program outside of the study, which were not supervised. Initially, the control group had 10 participants but there were two drops out, a man and a woman, because of illness and pregnancy, respectively.

Testing sessions

Firstly, all the participants performed an incremental test on a cycle ergometer (Excite Unity 3.0; Technogym S.p.A, Cesena, Italia) to determine peak power output (PPO) and peak oxygen consumption (VO_{2peak}) using a gas collection system (PNOE, Athens, Greece) that was calibrated in each test by means of ambient air. The PNOE system has proven its validity and reliability (*Tsekouras et al., 2019*). Before starting the test, capillary blood glucose concentrations were checked by their own blood glucose monitoring devices. They were told to arrive at the institutional gym with a glycemic level >100 mg/dl and less than 300 mg/dl in absence of ketones. If the glycemia was correct, the participant began the test normally. If not, the intake of 15–30 g of fast-acting carbohydrates (CHO) we had available was compulsory when glycemia was <100 mg/dl and a small corrective insulin dose was used if hyperglycemia occurred without ketones. In the presence of ketones the exercise was canceled. Glycemia was checked again until the level of blood glucose was optimum to start the test. In the same way, it was recommended that patients not exercise at the peak of insulin action (*Scott et al., 2019*).

The test consisted in a warm-up of 5 min at 40 Watts (W). After that, the workload was increased by 20 W every minute until exhaustion. Participants were verbally encouraged to give their maximum effort during the exercises. The test ends with a cool down of 5 min at 40 W. Heart rate was continuously monitored by a Polar H10 (Polar Electro, Kempele, Finland). VO_{2peak} was taken as the highest mean achieved within the last 15 s prior to exhaustion. Peak power output was registered to individualize the workloads in the experimental period training.

The hour of the day that each subject completed the test was recorded, as well as the menstrual phase of each female participant with the aim of repeating the same conditions in the second measurement to prevent their influence on the outcomes.

A total of 48 h after incremental testing, all the participants performed familiarization sessions to learn the correct technique to squat, as needed. This session consisted of the proper execution of the squat in a Smith machine and a reproduced experimental condition was taught, all monitored by the main researcher who is a strength and conditioning specialist. A week after the first test, the participants returned to the laboratory to perform three functional tests to measure lower limb strength, ankle dorsiflexion and dynamic balance: execution velocity performing squats with three different overloads; Weight Bearing Lunge Test (WBLT) and Y-Balance Test (YBT). The order of measurements was randomly counterbalanced to avoid any influence between them. Ten minutes of rest was set between tests to ensure the absence of all carry over effects.

Lower limb muscle power was measured by the execution velocity in the squat movement conducted in a Smith machine with no counterweight mechanism (Technogym S.p.A, Cesena, Italia) with overloads of 50%, 60% and 70% of the own body mass of each participant. The device selected to automatically calculate kinematic parameters of every repetition was an Encoder Speed4lift (Speed4lift S.L, Madrid, Spain). The encoder has proven its validity and reliability (*Pérez-Castilla et al., 2019*). After watching a standard video demonstration all the participants began a standard warm-up consisting of joint mobility, dynamic flexibility squats and lunges. After that, participants were required to perform three squats repetitions with each overload, conducting the concentric phase at maximal intended velocity and eccentric phase at controlled velocity. Subjects were instructed to perform parallel squats: descend until the inguinal crease was in projection with the top of the knee. Verbal and visual feedback was provided real-time to ensure the correct execution of the movement (*Pallarés et al., 2020*). The three sets were separated by 5-min rests to avoid the possible fatigue effect. Participants completed the test barefoot to avoid footwear influencing in the squat velocity. The data recorded and subsequently statistically analyzed were those corresponding to the highest execution velocity of the three repetitions in the concentric phase of the squat of each overload measured.

The WBLT was performed to determine the ankle joint dorsiflexion range of motion. A tape line was placed on the floor perpendicular to the wall, where a vertical line was taped. Participants placed both hands on the wall in front of them and then aligned the center of the heel and the second toe of the foot that was being tested over the tape line. WBLT was conducted with the subjects barefoot to eliminate any influence of the footwear. Participants were asked to lunge forward trying to touch the vertical line on the wall with their knee without lifting the heel of the tested foot off the ground, but no encouragement was provided during the testing. Touching the vertical line perpendicular to the floor with the knee among the line formed by the heel and the second toe, helped to control subtalar joint movement and standardized the test between participants. The contralateral limb was positioned behind the testing limb in a comfortable position. The participants were allowed to perform three practice trials before the three test trials to achieve the farthest distance from the wall to the first toe, with 30-s rests between tests. The measurement was taken between the big toe and the wall, to the nearest 0.1 cm using a standard tape measure secured to the floor. The average of the three trials scores was documented as the test result. Both feet were measured (*Hall & Docherty, 2017*; *Langarika-Rocafort et al., 2017*; *Powden, Hoch & Hoch, 2015*; *Searle, Spink & Chuter, 2018*).

Finally, the YBT was conducted using a reliable standardized protocol. A "Y" was marked with tape on the lab floor to measure the dynamic balance in the Anterior (A), Posterolateral (PL) and Posteromedial (PM) directions. The posterior lines were marked 135° from A line, with 90° between them. Before testing, the participants performed 10 min of standardized warm-up, with 5 min of submaximal cycling followed by a dynamic stretch routine consisting of functional exercises: front-to back leg swing, side-to-side leg swing, lateral lunge, and sumo squat to stand (*Benis, Bonato & La Torre, 2016*), the participants were allowed to practice six times with each leg in each direction to minimize the learning effect. Afterwards, participants were asked to stand barefoot on one leg with the midfoot positioned over the central point and to reach with the contralateral leg as far as possible while hands were placed on the wing of the ilium. The reach distance was measured by marking the tape measure with erasable ink at the point where the most distant part of the foot reached. The trial was discarded and repeated if the subject (1) made a heavy touch, (2) rested the foot on the ground, (3) lost balance, or (4) failed to return to the starting position in a controlled manner. The process was repeated while standing on the other leg. The testing order was three trials standing on the right foot while reaching with the left foot in the A direction, followed by three trials standing on the left foot and reaching with the right foot in the A direction. The procedure was repeated for the PM and then the PL-reach directions. This order was proposed to avoid fatigue. The YBT scores were analyzed using the average of the last three trials for each reach direction for each lower extremity. Those values were normalized to the height of each participant which was measured with tallimeter (Seca™

709, Hamburg, Germany) (*Benis, Bonato & La Torre, 2016*; *Gribble & Hertel, 2003*; *Linek et al., 2017*; *Plisky et al., 2009*; *Shah et al., 2017*).

All tests were performed under similar environmental conditions (22 ± 1 °C, 40–60% humidity). The same test protocols were performed in exactly the same way after the experimental period by both control and HIIT groups.

Training protocol

Training started the following week after completion of the pre-experimental procedures. Participants of the experimental group trained three times per week for 6 weeks under researcher supervision on a cycle ergometer (Excite Unity 3.0; Technogym S.p.A, Cesena, Italy). Heart rate while exercising was monitored with a Polar H10 (Polar Electro, Kempele, Finland) that was preconfigured with their heart rate zones. HIIT was a 1:2 protocol, which means that the high-intensity intervals lasted exactly half the time that the rest intervals did. The saddle height was always adjusted to the height of the subject's iliac crest. The training began with a 5-min warm-up at 50 W. Then, they performed repeated 30-s bouts of high-intensity cycling at a workload selected to elicit 85% of their individual PPO interspersed with 1 min of recovery at 40% PPO. The number of high-intensity intervals increased from twelve reps in weeks 1 and 2, to 16 reps in weeks 3 and 4, to 20 reps in weeks 5 and 6. Training ended with a 5-min cool down performed at 50 W. All sessions were supervised by, at least, a researcher. After the session, participants were told to check their glycemia level frequently and notify the investigators if a glycemia drop below 70 mg/dl occurred during the 24 h following the exercise (*Riddell et al., 2017*).

All sessions were supervised by the investigators and in order to reflect a real-world settings, researchers did not give advice about decreasing fast-acting insulin dosage or increasing carbohydrate consumption prior to each exercise session. Volunteers were only asked to arrive with glycemia <100 mg/dl (*Farinha et al., 2019*). Glucose levels were checked at least before and immediately after each exercise session, it was re-checked when glucose was not in the safety range. Fast-acting carbohydrates (15–30 g) were ingested when glycemia fell to ≤100 mg/dl. Hyperglycemia (250–300 mg/dl) was not set as a reason for postponing exercise if the patient felt well and ketones were negative (*Farinha et al., 2018*; *Scott et al., 2019*).

Statistical analysis

All variables were expressed as a mean and standard deviation (M ± SD) and were analyzed using a statistical package (SPSS Inc., Chicago, IL, USA). Normality assumption by Shapiro–Wilks was identified for each variable. A mixed factorial ANOVA (2 × 2) was performed to assess the influence of "*condition*" (i.e., control group vs. experimental group) and "*time moment*" variable (i.e., pre-intervention, post-intervention) over Lower limb muscle power (LLS), Y-balance test (YBT), and Weight bearing lunge test (WBLT). In the event that Sphericity assumption was not met, freedom degrees were corrected using Greenhouse-Geisser estimation. Post Hoc analysis was corrected using Bonferroni adjustment. Hedges' G and the associated CI were used to assess the magnitude of mean differences between control vs. experimental conditions. Significant differences were established at $p < 0.05$.

RESULTS

The results of our study show the significant improvement, in all variables studied, obtained by the experimental group, while in the control group no change was observed between pre- and post-intervention conditions.

There were three mild hypoglycemia cases (67.9 ± 2.6 mg/dl) of 198 total trainings (1.5%), occurring immediately after exercise which only required a few minutes of rest and carbohydrate ingestion to be solved. No adverse cardiac events, respiratory events or musculoskeletal injuries were reported in the experimental period. There were no episodes of hyperglycemia, nocturnal hypoglycemia or episodes of diabetic ketoacidosis.

Lower limbs muscle power

Lower limb Muscle Power experienced significant changes after the HIIT training period. With 50% of their body mass as additional load, the participants in the experimental group increased their speed of execution in squatting by 10.1%, the result of the mixed factorial ANOVA was $F(1,17) = 13.63$, $p = 0.02$. For 60% of the mass, by 9.4%, the result of the mixed factorial ANOVA was $F(1,17) = 13.56$, $p = 0.02$ and for 70%, there was an improvement of 10.1%, the result of the mixed factorial ANOVA was $F(1,17) = 20.21$, $p = 0.00$. In the control group, there were no significant changes between pre and post intervention assessment.

Y-balance test

In the dynamic equilibrium, measured by the YBT, there were changes between both assessments in the experimental group (pre-post intervention). For the right leg, there was a significant increase ($p < 0.05$) of 4.2%, the result of the mixed factorial ANOVA was $F(1,17) = 7.1$, $p = 0.02$, and 3.4%, the result of the mixed factorial ANOVA was $F(1,17) = 4.73$, $p = 0.04$, in the anterior and posterolateral direction respectively.
In contrast, in the posteromedial direction there was no significant change for this leg (1.9%). On the other hand, in the left leg, in the anterior direction there was an improvement of 6.1%, the result of the mixed factorial ANOVA was $F(1,17) = 13.6$, $p = 0.02$, in the posterolateral one there was an improvement of 4.5%, the result of the mixed factorial ANOVA was $F(1,17) = 9.1$, $p = 0.01$, and in the posteromedial one of 5.2%, the result of the mixed factorial ANOVA was $F(1,17) = 16.17$, $p = 0.01$. The control group experienced no change between the two assessments ($p > 0.05$). Data are presented in Table 2.

Weight bearing lunge test

Ankle dorsiflexion improved by 15.4% in the left foot of the participants, the result of the mixed factorial ANOVA was $F(1,17) = 11.33$, $p = 0.04$, and by 11.3% in the right foot in the experimental group (pre-post intervention), the result of the mixed factorial ANOVA was $F(1,17) = 19.67$, $p = 0.00$. The control group experienced no change between the two assessments. Data are presented in Table 3.

Table 2 Y-balance test results.

Y-balance test	HIIT group (n = 11)		Control group (n = 8)		Size effect
	Pre	Post	Pre	Post	
Anterior-right (cm)	41.81 ± 2.28	43.61 ± 2.78*	46.74 ± 5.56	47.20 ± 4.97	0.32 [−1.32 to 0.67]
Posterolateral-right (cm)	47.08 ± 5.54	48.68 ± 5.08*	45.91 ± 5.78	45.39 ± 3.35	0.36 [−1.38 to 0.66]
Posteromedial-right (cm)	52.47 ± 4.82	53.49 ± 5.34	48.96 ± 6.71	48.93 ± 7.36	0.18 [−1.09 to 0.74]
Anterior-left (cm)	44.94 ± 4.75	47.68 ± 4.87*	50.52 ± 8.80	51.17 ± 6.34	0.30 [−1.28 to 0.68]
Posterolateral-left (cm)	50.97 ± 5.54	53.30 ± 4.98*	49.85 ± 4.70	50.29 ± 4.54	0.35 [−1.36 to 0.67]
Posteromedial-left (cm)	49.20 ± 6.11	51.83 ± 5.45*	46.43 ± 4.73	46.45 ± 3.76	0.45 [−1.54 to 0.65]

Notes:
* Statistical significance between pre-post within groups $p < 0.05$.
Data are presented in mean ± standard deviation in centimeters (cm).

Table 3 Weight bearing lung test results.

Weight bearing lung test	HIIT group (n = 11)		Control group (n = 8)		Size effect
	Pre	Post	Pre	Post	
Right (cm)	11.5 ± 3.9	12.8 ± 3.4*	11.0 ± 1.9	10.4 ± 2.2	0.56 [−1.76 to 0.64]
Left (cm)	11.03 ± 3.3	12.7 ± 3.1*	12.1 ± 1.5	11.6 ± 1.7	−0.77 [−2.18 to 0.65]

Notes:
* Statistical significance between pre-post within groups $p < 0.05$.
Data are presented in mean ± standard deviation in centimeters (cm).

DISCUSSION

Our study demonstrates that a 6-week HIIT protocol is sufficient to result in functional capacity improvements in a previously inactive T1DM population without clinical impairments. Moreover, the study showed that this training method is safe for this population in field training since no insulin adjustments needed.

Only 3 of 198 total trainings, what means less than 1.5%, resulted in hypoglycemia, and they were mild cases (69.7 ± 2.6 mg/dl). These data suggest that HIIT prevents the blood glucose level dropped as well as previous studies reported and which is associated with catecholamine releasing and subsequent increase in hepatic glucose production which offsets the effect of hyperinsulinemia (*Boff et al., 2019*; *Farinha et al., 2017*, *2018*; *Scott et al., 2018*).

Impairments to skeletal muscle health in T1DM are, in many ways, similar to that observed in the muscle of aged individuals, but are occurring at a younger age in T1DM and compromises skeletal muscle function, sometimes since childhood (*Krause, Riddell & Hawke, 2011*; *Monaco, Gingrich & Hawke, 2019*). Our data is in agreement with previous research where reported the beneficial effects of applying HIIT in aging men was reported. Different studies by Peter Herbert and coworkers from different universities of the United Kingdom and Australia investigated the effect of HIIT performed on a cycle ergometer, as we did, on peak muscular power in both sedentary and active aging men. Given that similarity between older and T1DM muscle functionality, the results of those studies are in line with ours, since they observed that HIIT (6 × 30-s bouts at 90% heart rate

reserve interspersed with 3-min active recovery) performed every 5 days, for 6 weeks, induces a 8% increase in relative PPO measured with an incremental test in male masters athletes (*Herbert et al., 2017*). Other similar studies from this group, this time with sedentary seniors subjects analyzed the effect of the same type of HIIT aforementioned in muscle strength, resulting in an increase 14–17% approximately in relative peak power output, measured with an incremental test as well (*Sculthorpe, Herbert & Grace, 2015*, *2017*). Before the HIIT protocol, all the participants performed 6 weeks of pre-conditioning exercise protocol to prepare them for the high-intensity exercise.
The mechanisms related to the lower limb muscle power gain after the HIIT protocol remain unclear, but we hypothesize that mechanic efficiency and neuromuscular capacity could be behind these adaptations (*Jabbour et al., 2017*; *Stöggl & Björklund, 2017*).

Despite the T1DM and age-related changes to muscle power manifests in an impairment of the functional fitness, no previous research has tested the hypothesis about the relationship between the HIIT performed in cycle ergometer and muscle power gains and improvement in functional movements in T1DM individuals.

To the best of our knowledge, this is the first study to investigate the impact of HIIT on lower limb muscle power in T1DM people. Our main result is that the subjects improved significantly their velocity in squat with the 50%, 60% and 70% of their own body mass overload respectively. Since squat movement pattern represents functional capacity in primary daily living tasks (*Myer et al., 2014*) such as sitting or standing up, our results show that people with T1DM improve those capacities through a 6-week HIIT protocol type 1:2 performed in cycle ergometer, which is accessible and safe for this population.

Additional findings of the present study show improvement in ankle dorsiflexion range of motion, confirming previously reported results of studies which observed that the ankle adopts a more dorsiflexed position with an increase in cycling intensity (*Bini & Diefenthaeler, 2010*; *Holliday et al., 2019*). In the current literature, there are no published investigations that analyze ankle dorsiflexion after a HIIT period in T1DM neither in healthy people either, so our results cannot be compared with previous ones. In this study, we found that a HIIT protocol performing 12–20 high-intensity intervals at 85% PPO and resting intervals at 40% PPO for eighteen sessions in 6 weeks was enough to improve ankle joint dorsiflexion in the right lower limb (10.4%) and in the left lower limb (15.4%) in T1DM people. We hypothesize that the difference in improvement between the left and right leg is due to the left being the non-dominant limb, with the exception of one woman, in the entire experimental sample, so that the initial performance in WBLT in that limb was worse than in the right one. This improvement is interesting because of a proper dorsiflexion range of motion is crucial to allow a correct functionality in daily living activities (*Medeiros & Martini, 2018*) and a very important factor in rehabilitation gait and for improved walking, particularly in clinical population (*Embrey et al., 2010*). It is also important to reduce the 12–25% risk that people with diabetes have to developing foot ulcers (*Searle et al., 2017*). It is possible to indicate that HIIT performed in cycle ergometer may be beneficial and an interesting tool for maintaining in non-impairment functionality in T1DM people.

Lastly, the results of this investigation have provided evidence that HIIT performed in cycle ergometer is an effective training strategy to improve dynamic balance in a T1DM population measured through YBT. Shorter reach distances performed in this test are typically associated with mechanical or sensorimotor system constraint (*Hoch, Staton & McKeon, 2011*) and reduced functionality to carry out daily living tasks (*Camargo et al., 2015*; *D'Silva et al., 2016*; *Shimada et al., 2003*; *Teyhen et al., 2014*). Data obtained with YBT reveals significant improvements in this test in both right and left limb. PM direction only was improved in the left limb (5.2%). Indeed, in A and PL directions important changes were reported in both limbs. Performance in those YBT directions are high correlated with ankle joint dorsiflexion (*Hoch, Staton & McKeon, 2011*; *Suryavanshi et al., 2015*), what is consistent with the results obtained in WBLT in which ankle dorsiflexion was increased by the participants. These results could show that people with T1DM without neuropathy can increase their dynamic balance end prevent future functional impairments and falls, given neuropathy development is not imperative to show reduced dynamic balance (*Abdul-Rahman et al., 2016*; *Kukidome et al., 2017*).

A possible explanation for the functional improvements could be, firstly, dorsiflexed position in cycling could be sufficient flexibility stimulus for reduced range of motion patients, and secondly for reducing glycation products in T1DM and in turn improving the joint health (*Abate et al., 2013*).

The practical implication of the present study is to bring inactive T1DM people closer to regular exercise. Our group has corroborated previous researches that reported HIIT as an effective training strategy to prevent hypo glycemia in T1DM people. Moreover, the functional improvements we have demonstrated using a 1:2 HIIT protocol indicate that it is a correct training prescription for T1DM people to start doing physical exercise. The results of this study demonstrate functional benefits of 6-week HIIT in cycle ergometer in T1DM subjects. Since there are no previous studies, our results should be taken with caution because this study has limitations that must be addressed. Limited sampled used with a specific range of age. We did not assess functional improvements in gait and finally we did no measure biomarkers related to the joint health in T1DM as the advanced glycation end-products (AGEs) that are actively produced and accumulated in the circulating blood and various tissues as tendons in chronic hyperglycemic situations as T1DM. As a contributing factor in T1DM complications its improvement could correlate with joint health. It also must be mentioned, that neuropathy increases the impairments in the capacities assessed in this work and it was not controlled given no participants were diagnosed with neuropathy. The control group did not perform any exercise during the experimental period, so their results were to be expected. Thus, it would be interesting to add a third group that performed continuous moderate exercise to analyze the difference with the HIIT group.

CONCLUSIONS

In conclusion, 6-week HIIT protocol 1:2 type, performing high-intensity intervals at 85% PPO and active rest intervals at 40% PPO in a cycle ergometer for three sessions per week, apart from being accessible and safe since participants were able to complete all the sessions with the intensity required without suffering any severe or undesirable episodes of hypoglycemia, was enough to improve lower limb muscle power, ankle joint dorsiflexion and dynamic balance in T1DM, which is related to an improvement in functionality in daily living activities. HIIT seems like an interesting approach for improving physical functionality in T1DM people.

ADDITIONAL INFORMATION AND DECLARATIONS

Funding

The authors received no funding for this work.

Competing Interests

The authors declare that they have no competing interests.

Author Contributions

- Jesús Alarcón-Gómez conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft.
- Fernando Martin Rivera conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft.
- Joaquin Madera performed the experiments, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft.
- Iván Chulvi-Medrano performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft.

Human Ethics

The following information was supplied relating to ethical approvals (i.e., approving body and any reference numbers):

The University of Valencia granted Ethical approval to carry out the study within its facilities (h1421157445503).

Data Availability

The following information was supplied regarding data availability:

The raw measurements are available in the Supplemental Files.

Supplemental Information

Supplemental information for this article can be found online at http://dx.doi.org/10.7717/peerj.10510#supplemental-information.

REFERENCES

Abate M, Schiavone C, Salini V, Andia I. 2013. Management of limited joint mobility in diabetic patients. *Diabetes, Metabolic Syndrome and Obesity: Targets and Therapy* **6**:197–207 DOI 10.2147/DMSO.S33943.

Abdul-Rahman RS, Ghait AS, Sherief AAA, AboGazy A. 2016. Postural control and balance assessment in children 15 years old with type 1 diabetes. *International Journal of Medical Research & Health Sciences* **5(12)**:65–69.

Bellumori M, Uygur M, Knight CA. 2017. High-speed cycling intervention improves rate-dependent mobility in older adults. *Medicine and Science in Sports and Exercise* **49(1)**:106–114 DOI 10.1249/MSS.0000000000001069.

Benis R, Bonato M, La Torre A. 2016. Elite female basketball players' body-weight neuromuscular training and performance on the Y-balance test. *Journal of Athletic Training* **51(9)**:688–695 DOI 10.4085/1062-6050-51.12.03.

Bini RR, Diefenthaeler F. 2010. Kinetics and kinematics analysis of incremental cycling to exhaustion. *Sports Biomechanics* **9(4)**:223–235 DOI 10.1080/14763141.2010.540672.

Boff W, Da Silva AM, Farinha JB, Rodrigues-Krause J, Reischak-Oliveira A, Tschiedel B, Puñales M, Bertoluci MC. 2019. Superior effects of high-intensity interval vs. moderate-intensity continuous training on endothelial function and cardiorespiratory fitness in patients with type 1 diabetes: A randomized controlled trial. *Frontiers in Physiology* **10(April)**:383 DOI 10.3389/fphys.2019.00450.

Buchheit M, Laursen PB. 2013. High-intensity interval training, solutions to the programming puzzle. Part II: anaerobic energy, neuromuscular load and practical applications. *Sports Medicine* **43(10)**:927–954 DOI 10.1007/s40279-013-0066-5.

Camargo MR, Barela JA, Nozabieli AJL, Mantovani AM, Martinelli AR, Fregonesi CEPT. 2015. Balance and ankle muscle strength predict spatiotemporal gait parameters in individuals with diabetic peripheral neuropathy. *Diabetes and Metabolic Syndrome: Clinical Research and Reviews* **9(2)**:79–84 DOI 10.1016/j.dsx.2015.02.004.

Celes R, Bottaro M, Cadore E, Dullius J, Schwartz F, Luzine F. 2017. Low-load high-velocity resistance exercises improve strength and functional capacity in diabetic patients. *European Journal of Translational Myology* **27(2)**:6292 DOI 10.4081/ejtm.2017.6292.

Codella R, Terruzzi I, Luzi L. 2017. Why should people with type 1 diabetes exercise regularly? *Acta Diabetologica* **54(7)**:615–630 DOI 10.1007/s00592-017-0978-x.

D'Silva LJ, Lin J, Staecker H, Whitney SL, Kluding PM. 2016. Impact of diabetic complications on balance and falls: contribution of the vestibular system. *Physical Therapy* **96(3)**:400–409 DOI 10.2522/ptj.20140604.

De Nardi AT, Tolves T, Lenzi TL, Signori LU, Da Silva AMV. 2018. High-intensity interval training versus continuous training on physiological and metabolic variables in prediabetes and type 2 diabetes: A meta-analysis. *Diabetes Research and Clinical Practice* **137**:149–159 DOI 10.1016/j.diabres.2017.12.017.

Embrey DG, Holtz SL, Alon G, Brandsma BA, McCoy SW. 2010. Functional electrical stimulation to dorsiflexors and plantar flexors during gait to improve walking in adults with chronic hemiplegia. *Archives of Physical Medicine and Rehabilitation* **91(5)**:687–696 DOI 10.1016/j.apmr.2009.12.024.

Farinha J, Boff W, Dos Santos GC, Boeno FP, Ramis TR, Vieira AF, Macedo RCO, Rodrigues-Krause J, Reischak-Oliveira A. 2019. Acute glycemic responses along 10-week high-intensity training protocols in type 1 diabetes patients. *Diabetes Research and Clinical Practice* **153**:111–113 DOI 10.1016/j.diabres.2019.06.001.

Farinha J, Krause M, Rodrigues-Krause J, Reischak-Oliveira A. 2017. Exercise for type 1 diabetes mellitus management: general considerations and new directions. *Medical Hypotheses* **104**:147–153 DOI 10.1016/j.mehy.2017.05.033.

Farinha J, Ramis TR, Vieira AF, Macedo RCO, Rodrigues-Krause J, Boeno FP, Schroeder HT, Müller CH, Boff W, Krause M, De Bittencourt PIH, Reischak-Oliveira A. 2018. Glycemic, inflammatory and oxidative stress responses to different high-intensity training protocols in type 1 diabetes: a randomized clinical trial. *Journal of Diabetes and Its Complications* **32(12)**:1124–1132 DOI 10.1016/j.jdiacomp.2018.09.008.

Francia P, Toni S, Iannone G, Seghieri G, Piccini B, Vittori A, Santosuosso U, Casalini E, Gulisano M. 2018. Type 1 diabetes, sport practiced, and ankle joint mobility in young patients: what is the relationship? *Pediatric Diabetes* **19(4)**:801–808 DOI 10.1111/pedi.12643.

Galassetti P, Riddell MC. 2013. Exercise and type 1 diabetes (T1DM). *Comprehensive Physiology* **3(3)**:1309–1336 DOI 10.1002/cphy.c110040.

Gribble PA, Hertel J. 2003. Considerations for normalizing measures of the Star Excursion Balance Test. *Measurement in Physical Education and Exercise Science* **7(2)**:89–100 DOI 10.1207/S15327841MPEE0702_3.

Hall EA, Docherty CL. 2017. Validity of clinical outcome measures to evaluate ankle range of motion during the weight-bearing lunge test. *Journal of Science and Medicine in Sport* **20(7)**:618–621 DOI 10.1016/j.jsams.2016.11.001.

Herbert P, Hayes LD, Sculthorpe NF, Grace FM. 2017. HIIT produces increases in muscle power and free testosterone in male masters athletes. *Endocrine Connections* **6(7)**:430–436 DOI 10.1530/EC-17-0159.

Hoch MC, Staton GS, McKeon PO. 2011. Dorsiflexion range of motion significantly influences dynamic balance. *Journal of Science and Medicine in Sport* **14(1)**:90–92 DOI 10.1016/j.jsams.2010.08.001.

Holliday W, Theo R, Fisher J, Swart J. 2019. Cycling: joint kinematics and muscle activity during differing intensities. *Sports Biomechanics* **191**:1–15 DOI 10.1080/14763141.2019.1640279.

Hussain SR, Macaluso A, Pearson SJ. 2016. High-intensity interval training versus moderate-intensity continuous training in the prevention/management of cardiovascular disease. *Cardiology in Review* **24(6)**:273–281 DOI 10.1097/CRD.0000000000000124.

International Diabetes Federation. 2019. *ATLAS DE LA DIABETES DE LA FID*. Ninth Edition. Brussels: International Diabetes Federation.

Jabbour G, Iancu HD, Mauriège P, Joanisse DR, Martin LJ. 2017. High-intensity interval training improves performance in young and older individuals by increasing mechanical efficiency. *Physiological Reports* **5(7)**:e13232 DOI 10.14814/phy2.13232.

Katsarou A, Gudbjörnsdottir S, Rawshani A, Dabelea D, Bonifacio E, Anderson BJ, Jacobsen LM, Schatz DA, Lernmark Å. 2017. Type 1 diabetes mellitus. *Nature Reviews. Disease Primers* **3(1)**:17016 DOI 10.1038/nrdp.2017.16.

Krause MP, Riddell MC, Hawke TJ. 2011. Effects of type 1 diabetes mellitus on skeletal muscle: clinical observations and physiological mechanisms. *Pediatric Diabetes* **12(4 Pt 1)**:345–364 DOI 10.1111/j.1399-5448.2010.00699.x.

Kukidome D, Nishikawa T, Sato M, Nishi Y, Shimamura R, Kawashima J, Shimoda S, Mizuta H, Araki E. 2017. Impaired balance is related to the progression of diabetic complications in both young and older adults. *Journal of Diabetes and Its Complications* **31(8)**:1275–1282 DOI 10.1016/j.jdiacomp.2017.05.014.

Langarika-Rocafort A, Emparanza JI, Aramendi JF, Castellano J, Calleja-González J. 2017. Intra-rater reliability and agreement of various methods of measurement to assess dorsiflexion in the Weight Bearing Dorsiflexion Lunge Test (WBLT) among female athletes. *Physical Therapy in Sport* **23**:37–44 DOI 10.1016/j.ptsp.2016.06.010.

Lascar N, Kennedy A, Hancock B, Jenkins D, Andrews RC, Greenfield S, Narendran P. 2014. Attitudes and barriers to exercise in adults with type 1 diabetes (T1DM) and how best to address them: a qualitative study. *PLOS ONE* **9(9)**:e108019 DOI 10.1371/journal.pone.0108019.

Leroux C, Brazeau A-S, Gingras V, Desjardins K, Strychar I, Rabasa-Lhoret R. 2014. Lifestyle and cardiometabolic risk in adults with type 1 diabetes: a review. *Canadian Journal of Diabetes* **38(1)**:62–69 DOI 10.1016/j.jcjd.2013.08.268.

Linek P, Sikora D, Wolny T, Saulicz E. 2017. Reliability and number of trials of Y Balance Test in adolescent athletes. *Musculoskeletal Science and Practice* **31**:72–75 DOI 10.1016/j.msksp.2017.03.011.

Lopez P, Pinto RS, Radaelli R, Rech A, Grazioli R, Izquierdo M, Cadore EL. 2018. Benefits of resistance training in physically frail elderly: a systematic review. *Aging Clinical and Experimental Research* **30**:889–899 DOI 10.1007/s40520-017-0863-z.

Medeiros DM, Martini TF. 2018. Chronic effect of different types of stretching on ankle dorsiflexion range of motion: systematic review and meta-analysis. *Foot* **34**:28–35 DOI 10.1016/j.foot.2017.09.006.

Monaco CMF, Gingrich MA, Hawke TJ. 2019. Considering Type 1 diabetes as a form of accelerated muscle aging. *Exercise and Sport Sciences Reviews* **47(2)**:98–107 DOI 10.1249/JES.0000000000000184.

Myer GD, Kushner AM, Brent JL, Schoenfeld BJ, Hugentobler J, Lloyd RS, Vermeil A, Chu DA, Harbin J, McGill SM. 2014. The back squat: a proposed assessment of functional deficits and technical factors that limit performance. *Strength and Conditioning Journal* **36(6)**:4–27 DOI 10.1519/SSC.0000000000000103.

Pallarés JG, Cava AM, Courel-Ibáñez J, González-Badillo JJ, Morán-Navarro R. 2020. Full squat produces greater neuromuscular and functional adaptations and lower pain than partial squats after prolonged resistance training. *European Journal of Sport Science* **20(1)**:115–124 DOI 10.1080/17461391.2019.1612952.

Papa EV, Dong X, Hassan M. 2017. Resistance training for activity limitations in older adults with skeletal muscle function deficits: a systematic review. *Clinical Interventions in Aging* **12**:955–961 DOI 10.2147/CIA.S104674.

Pérez-Castilla A, Piepoli A, Delgado-García G, Garrido-Blanca G, García-Ramos A. 2019. Reliability and concurrent validity of seven commercially available devices for the assessment of movement velocity at different intensities during the bench press. *Journal of Strength and Conditioning Research* **33(5)**:1258–1265 DOI 10.1519/JSC.0000000000003118.

Plisky PJ, Gorman PP, Butler RJ, Kiesel KB, Underwood FB, Elkins B. 2009. The reliability of an instrumented device for measuring components of the star excursion balance test. *North American Journal of Sports Physical Therapy: NAJSPT* **4(2)**:92–99.

Powden CJ, Hoch JM, Hoch MC. 2015. Reliability and minimal detectable change of the weight-bearing lunge test: a systematic review. *Manual Therapy* **20(4)**:524–532 DOI 10.1016/j.math.2015.01.004.

Rao SR, Saltzman CL, Wilken J, Yak HJ. 2006. Increased passive ankle stiffness and reduced dorsiflexion range of motion in individuals with diabetes mellitus. *Foot and Ankle International* **27(8)**:617–622 DOI 10.1177/107110070602700809.

Riddell MC, Gallen IW, Smart CE, Taplin CE, Adolfsson P, Lumb AN, Kowalski A, Rabasa-Lhoret R, McCrimmon RJ, Hume C, Annan F, Fournier PA, Graham C, Bode B, Galassetti P, Jones TW, Millán IS, Heise T, Peters AL, Petz A, Laffel LM. 2017. Exercise management in type 1 diabetes: a consensus statement. *Lancet. Diabetes & Endocrinology* **5(5)**:377–390 DOI 10.1016/S2213-8587(17)30014-1.

Scott SN, Cocks M, Andrews RC, Narendran P, Purewal TS, Cuthbertson DJ, Wagenmakers AJM, Shepherd SO. 2018. High-intensity interval training improves aerobic capacity without a detrimental decline in blood glucose in people with Type 1 diabetes. *Journal of Clinical Endocrinology and Metabolism* **104(2)**:604–612 DOI 10.1210/jc.2018-01309.

Scott SN, Cocks M, Andrews RC, Narendran P, Purewal TS, Cuthbertson DJ, Wagenmakers AJM, Shepherd SO. 2019. High-intensity interval training improves aerobic capacity without a detrimental decline in blood glucose in people with Type 1 diabetes. *The Journal of Clinical Endocrinology & Metabolism* **104(2)**:604–612 DOI 10.1210/jc.2018-01309.

Sculthorpe NF, Herbert P, Grace F. 2017. One session of high-intensity interval training (HIIT) every 5 days, improves muscle power but not static balance in lifelong sedentary ageing men. *Medicine* **96(6)**:e6040 DOI 10.1097/MD.0000000000006040.

Sculthorpe N, Herbert P, Grace FM. 2015. Low-frequency high-intensity interval training is an effective method to improve muscle power in lifelong sedentary aging men: a randomized controlled trial. *Journal of the American Geriatrics Society* **63(11)**:2412–2413 DOI 10.1111/jgs.13863.

Searle A, Spink MJ, Chuter VH. 2018. Weight bearing versus non-weight bearing ankle dorsiflexion measurement in people with diabetes: a cross sectional study. *BMC Musculoskeletal Disorders* **19(1)**:183 DOI 10.1186/s12891-018-2113-8.

Searle A, Spink MJ, Ho A, Chuter VH. 2017. Association between ankle equinus and plantar pressures in people with diabetes: a systematic review and meta-analysis. *Clinical Biomechanics* **43**:8–14 DOI 10.1016/j.clinbiomech.2017.01.021.

Shah KC, Peehal JP, Shah A, Crank S, Flora HS. 2017. Star excursion balance test for assessment of dynamic instability of the ankle in patients after harvest of a fibular free flap: a two-centre study. *British Journal of Oral and Maxillofacial Surgery* **55(3)**:256–259 DOI 10.1016/j.bjoms.2016.11.007.

Shimada H, Obuchi S, Kamide N, Shiba Y, Okamoto M, Kakurai S. 2003. Relationship with dynamic balance function during standing and walking. *American Journal of Physical Medicine & Rehabilitation* **82(7)**:511–516 DOI 10.1097/01.PHM.0000064726.59036.CB.

Stöggl TL, Björklund G. 2017. High intensity interval training leads to greater improvements in acute heart rate recovery and anaerobic power as high volume low intensity training. *Frontiers in Physiology* **8(August)**:562 DOI 10.3389/fphys.2017.00562.

Suryavanshi P, Kumar A, Kulkarni P, Patel P. 2015. Correlation of ankle dorsiflexion range of motion with dynamic balance in young normal individuals. *International Journal of Physiotherapy and Research* **3(4)**:1184–1187 DOI 10.16965/ijpr.2015.166.

Teyhen DS, Shaffer SW, Lorenson CL, Greenberg MD, Rogers SM, Koreerat CM, Villena SL, Zosel KL, Walker MJ, Childs JC. 2014. Clinical measures associated with dynamic balance and functional movement. *Journal of Strength and Conditioning Research* **28(5)**:1272–1283 DOI 10.1519/JSC.0000000000000272.

Tsekouras YE, Tambalis KD, Sarras SE, Antoniou AK, Kokkinos P, Sidossis LS. 2019. Validity and reliability of the new portable metabolic analyzer PNOE. *Frontiers in Sports and Active Living* **1**:24 DOI 10.3389/fspor.2019.00024.

Turcot K, Allet L, Golay A, Hoffmeyer P, Armand S. 2009. Investigation of standing balance in diabetic patients with and without peripheral neuropathy using accelerometers. *Clinical Biomechanics* **24(9)**:716–721 DOI 10.1016/j.clinbiomech.2009.07.003.

Vinik AI, Camacho P, Reddy S, Valencia WM, Trence D, Matsumoto AM, Morley JE. 2017. Aging, diabetes, and falls. *Endocrine Practice* **23(9)**:1120–1142 DOI 10.4158/EP171794.RA.

WHO. 2016. *Informe mundial sobre la diabetes*. Geneva: WHO. *Available at https://www.who.int/diabetes/global-report/es/*.

Wu R, Zhang Y, Bai JJ, Sun J, Bao ZJ, Wang Z. 2020. Impact of lower limb muscle strength on walking function beyond aging and diabetes. *Journal of International Medical Research* **48(6)**:030006052092882 DOI 10.1177/0300060520928826.

Yardley JE, Hay J, Abou-Setta AM, Marks SD, McGavock J. 2014. A systematic review and meta-analysis of exercise interventions in adults with type 1 diabetes. *Diabetes Research and Clinical Practice* **106(3)**:393–400 DOI 10.1016/j.diabres.2014.09.038.

You WP, Henneberg M. 2016. Type 1 diabetes prevalence increasing globally and regionally: the role of natural selection and life expectancy at birth. *BMJ Open Diabetes Research and Care* **4(1)**:e000161 DOI 10.1136/bmjdrc-2015-000161.