Title page

Impact of plantar fasciitis on postural control and walking in young middle-aged adults

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Abstract

Purpose: To assess if plantar fasciitis has an impact on postural control and walking pattern from gait analysis across different experimental conditions.

Methods: Thirty participants (n =15 with plantar fasciitis) performed 5 different balance tasks on a force platform, and the center of pressure (COP) was computed for postural control analysis. Participants were also asked to walk at 3 different speeds on a gait analysis system to compute the spatial-temporal parameters. Clinical foot measurements (pain, mobility) were also collected through all participants.

Results: Clinical foot measurements showed no significant difference between the two groups; except for pain palpation in plantar fasciitis group. Significant differences were observed between the two groups for COP area displacement sway ($p < 0.01$; $d = 0.08$) and velocity ($p = 0.022$; $d = 0.04$), where the fasciitis group reported poorer postural control than control mainly during more challenging balance tasks (semi-tandem, unipodal). Plantar fasciitis group reported a decrease of gait velocity ($p < 0.01$; $d = 0.12$), step length ($p < 0.01$; $d = 0.16$) and step width ($p < 0.01$; $d = 0.18$) when compared to the healthy group across walking speed tests.

Conclusions: Individuals with plantar fasciitis report poor postural control and changes in walking pattern across three speeds performance.

Key words: Foot, Biomechanics, Rehabilitation, Balance, Gait, Plantar fasciitis

INTRODUCTION

The plantar fascia is made up of collagen fiber split into three bands connecting the medial tuberosity of the calcaneum to the metatarsal heads in continuity with the Achilles tendon [1] and with the function of support for plantar arches and the transfer of forces during the different cycles of gait [1,2]. However, the self-perceived pain in the plantar part of the heel is often caused by micro tears in the plantar fascia, including these passive structures similar to a tendon injury often called classic foot plantar disorder [3]. Fascia injuries can be due to multiple causes and explained by intrinsic, extrinsic, or the sum of several risk factors such as overuse, overweight, prolonged weight-bearing, limited ankle joint dorsiflexion, muscular weakness, and unbalance [3]. In addition, aging is related to degenerative processes and chronic diseases or systemic conditions such as diabetes [4] or rheumatologic predictors of plantar fasciitis [5]. Type of foot, lifestyle, and occupation are other factors that can increase plantar dysfunction [3,6].

Plantar fasciitis is a common musculoskeletal foot disorder [7], with a prevalence of 7% across adults [3]. This disorder can equally affect both men and women [3] and is prevalent in adults aged 45 to 64 [8]. A plantar fasciitis diagnosis is primarily based on the history of pain (i.e., frequently present in the morning during the first steps or in a prolonged upright posture with overload) reported by the patient, as well as on the pain perceived during palpation of the medial tuberosity of the calcaneum [8]. Pain during palpation can be exacerbated by active plantar flexion of the foot or passive dorsiflexion [9]. Imagery can also be used to clarify the diagnosis, such as using an ultrasound system [10]. The ultrasound allows to assess the thickness of the fascia, the presence of tears, and the swelling of the tissues, which could be injured with the fasciitis [10]. X-ray is another method but only allows to observe the presence of a calcaneal spur with no relation to pain [10]. Presence or absence of a calcaneal spur does not allow to establish a diagnosis of plantar fasciitis, since its presence is not related to the onset of pain [10]. The pathogenesis of plantar fasciitis is like tendinosis. Effectively, when there is an overload or excessive strain on the plantar facia, this produces microtears, activating the inflammatory response. Since the traumas are repeated at each step, inflammation becomes chronic and degenerative changes occur in the plantar fascia, especially in the collagen fiber [9,11]. However, inflammatory cells are not always present in the injured tissue, such as in chronic tendon disorders which are more like tendinosis than tendinitis [11].

Overall, the main physical limitations are associated with fasciitis and muscular weakness [12], reduction of fascia elasticity [13], and finally tension in the Achilles tendon [14]. These limitations can further cause proprioception impairment and, consequently, poor postural balance, increasing the risk of falls in older people [12,13,15]. In fact, in the presence of plantar fasciitis, thickening of the fascia leads to a loss of elasticity, which directly interferes with the transfer of forces from the back to the front of the foot, consequently affecting proprioception and balance performance [13]. Therefore, increased tension in the Achilles tendon can affect the plantar fascia, due to reduced height of the arch and increased pressure on the forefoot [14].This phenomenon can impact both static and dynamic balance control [12,13,15].

Although plantar fasciitis affects balance, nothing is known about its impact on walking, based in spatial-temporal gait analysis. It would be interesting to generalize the few findings in literature on a same experimental design using both postural control outcomes from Center of Pressure (COP) measurement under force platform and gait parameters (i.e., cadence, velocity, and other things). In fact, no study has compared the effect of this disorder on static and dynamic task conditions related to balance and walking, which are indispensable for an individual’s functionality from activities of daily life. Or, balance and walking are often used to determine individual functionality, prevent disability and mainly future risk of falls associated with the aging process. Thus, to better answer this literature from a more robust experimental protocol and to complete the results from other authors that have assessed only static balance conditions [13], the present study aimed to assess, for the first time, the impact of plantar fasciitis on postural control during five balance tasks and on walking performance across three different gait speed analysis in early middled-aged adults. For both conditions, it was expected that individuals suffering from plantar fasciitis would present poor postural control and changes on walking pattern as compared to healthy-control.

MATERIALS AND METHODS

Study design

An experimental cross-sectional design was performed between October 2020 and March 2021 at the *Clinique universitaire de physiothérapie of* the XXX in collaboration with the *Clinique podiatrique du Saguenay.*

Participants

A total of 30 participants separated into two group of 15, the pathological group (with plantar fasciitis) and the control group (without plantar fasciitis) were selected among the voluntary population from local community. A power sample calculation was based on a previous study [13] and allowed us to say that our sample was enough with a significant level of 0.05 and a power of 0.80. From the mean values of the center of pressure sway under force plate during a tandem (feet apart) balance task with eyes closed in adults with plantar fasciitis (10.91 ± 8.56 cm^2) vs. without pathology (4.67± 1.58.5 cm^2), with Cohen's *d* (effect size) = 1.01, 30 participants would be needed (n = 15 with plantar fasciitis) to run an unpaired t-test between the groups (95% CI) with a power of 0.80.

The general inclusion criteria were being an adult man or woman aged 18 years +. Concerning the pathological group, the specific inclusion criteria were a diagnosis of plantar fasciitis, based on the history of pain (i.e., frequently present in the morning during the first steps or a prolonged upright posture with overload) reported by the patient, as well as the pain perceived during palpation of the medial tuberosity of the calcaneum [8], within the past three months by a doctor specializing in podiatric medicine working at the *Clinique podiatrique du Saguenay (Saguenay, QC, Canada).* The general exclusion criteria were having (1) surgery of the locomotor system (2) a malformation of the locomotor system (ex: intervertebral fusion), (3) diseases or syndromes that can affect the musculoskeletal, cardiovascular, respiratory, or nervous system, (ex: rheumatism, multiple sclerosis, fibromyalgia), (4) history of neurological conditions, without relation with foot problems (stroke, balance trouble) or vestibular damage (dizziness), (5) be unable to achieve the balance tasks, (6) undergoing medical treatment for plantar fasciitis at the time of testing.

The research project received ethical approval from the Human Research Ethics Committee at the XXX, Quebec, Canada (ethical certification number: 2020-404). Each participant signed the informed consent before their participation.

Procedure

The selection of the pathological participants was first established at the *Clinique podiatrique du Saguenay*, after all participants had participated in a one-hour laboratory session to sign the informed consent and data collection permission. All participants must complete a general survey and the Q-AAP (Questionnaire d'Aptitude à l'Activité Physique). After that, clinical foot measurements (detailed below), different static balance tasks, and walking measurements were performed. First, anthropometric measurements (height, weight, body mass index) were collected, followed by feet posture analysis, balance and gait measures.

Clinical measurements

Clinical measurements for the foot were (Figure 1):

Clinical measurements for the feet were (figure 1) arch height, calcaneum's neutral position, and range of motion. The arch height was measured by a ruler (± 0,5 mm); the reference point was the height of the prominence of the navicular. The evaluator put a dot on the prominence of the navicular and took the measurement between the dot and the floor [16]. The neutral position of the calcaneum (NPC) in charge was performed with a goniometer. The angulation between the bisection of the calcaneum and the perpendicular to the floor was also measured [16,17]. This measure allows to classify the foot, a NPC inferior to 4 degrees valgus is a flat foot, a NPC between 4-degree valgus and 4-degree varus is a neutral foot and a NPC superior to 4-degree varus is a cavus foot [16]. The maximum of Range of Motion (ROM) in dorsiflexion at the first metatarsophalangeal joint (MPJ) [18] and the ankle joint was also assessed by a goniometer (± 0.5°) from the Silverskiold test [6].

Clinical measurements for balance and gait were (Figure 2):

For the static balance tests, the force plate – BIOMEC 400 (EMG system do Brasil, SP, Ltda) was used to quantify the vertical ground reaction force signals from sampled at 100 Hz. All force signals were filtered with a 35-Hz low-pass second-order Butterworth filter and converted into COP data using proper software, compiled with MATLAB routines (The Mathworks, Natick, MA). Afterward, stabilographic analysis of COP data led to the calculation of the two main postural control parameters across balance conditions [19] (1) 95% confidence ellipse area of COP (Area COP in cm^2), (2) mean velocity (VEL COP in cm/s) and (3) mean frequency (in Hz) for both anteroposterior (A/P) and mediolateral (M/L) directions of movement. For all balance tests, COP parameters were calculated for each subject's total duration of the trial. The validity and reliability of these parameters have been adequate (ICC > 0.85) for postural control analysis in different balance conditions [19,20].

For walking analysis during the study, the GaitRite system (GAITRite® Platinum Plus System 16' – 4.876 m, SN: Q209, CIR Systems Inc., Franklin, NJ, USA) was used. This system is comprised of an electronic mat that allows to take spatial and temporal gait measurements with a frequency sampling of 100Hz. During the experimental conditions, the main variables computed across three speeds were: Velocity (cm/s), cadence (step/min), step length (cm), and step width (cm) [21,22]. These gait parameters from GaitRite system report an excellent concurrent validity (ICC = 0.91–0.99) when compared to Vicon5121 system [22] as well as an excellent reliability in test-retest measurements (ICC = 0.85–0.93; [23]. In general, the reliability of this system (GAITRite® Platinum Plus System 16' – 4.876 m, SN: Q209, CIR Systems Inc., Franklin, NJ, USA) was found to be excellent for both young and older adults [24,25], supporting their utilization for the first time in individuals with plantar fasciitis.

Experimental protocol

After familiarization, all participants had to carry out five different tasks on the force platform (Figure 2). Each task was standardized; participants were barefoot, with arms along the body. Three different foot positions were performed: Bipodal (BP), semi-tandem (ST) (the front foot was chosen by the participant) and unipodal (UP) (the participants chose the support foot from preferred leg). For the bipodal and semi-tandem positions, the task was performed with eyes open (BPEO and STEO) and closed (BPEC and STEC). During the condition with their eyes open, participants had to look at a target that was on a wall 2 m away at eye-level [26,27]. Participants performed two 30-second trials for each balance task, and the average was retained for subsequent analysis [19,27]. An evaluator was near at all times to prevent fall risk, and the tasks were presented randomly for all participants [26,27].

For gait analysis, the participants performed three conditions on walking system: 1) Preferred speed (PS) walk (speed usually used for daily activities), 2) reduced speed (RS) walk (slower than usual speed) and 3) fast speed (FS) walk (faster than usual speed). These three conditions were randomized and performed across 2 trials [24]. The mean from trials was used for analysis. A short time of rest (30 sec.) was applied between each condition. Again, one evaluator performed the walk in parallel to the system so the participant would feel more secure and to prevent any risk of falling.

Statistical analysis

All statistical analyses were performed with IBM® SPSS 20 software with an alpha level of 0.05. The normality of each variable was calculated with the Shapiro-Wilk test to determine which statistical analysis would be used. Overall, the Student’s *t*-test was used to compare the anthropometric measurements and the clinical foot measurements across two groups (pathological vs. control). Two-way ANOVA with repeated measurements were used to evaluate the effects on two groups (group factor comparison) and to differences from balance and walking tasks (condition factor comparison for balance and walking) and the effects of interactions between them for each dependent variable (COP and gait parameters). When necessary, post hoc analysis, using the Tukey test was used to localise the differences between conditions (balance tasks or speed conditions when walking was analysed). The effect size (ES) of Cohen was also calculated when significance was obtained for any comparisons from the main variables investigated on ANOVA to determine the magnitude of changes [28]. The effect size was characterized as weak, moderate and strong effects, i.e., $d = 0.2$ is small, $d = 0.5$ medium and $d = 0.8$ large, respectively. Finally, ANCOVA analysis on main factors was applied if necessary to validate that the results are not confounded by age or BMI differences between groups.

RESULTS

Table 1 presents participant characteristics data (age, height, weight, and BMI). Significant differences between groups were reported for age ($p < 0.01$) and weight ($p = 0.035$), except for height ($p = 0.887$) and for BMI variables ($p = 0.051$).

Clinical foot measurements

The results showed no statistically significant difference between the two groups for all variables, except for pain related to palpation (see Table 2). Pain reported for the pathological group was 3/10 for the left foot and 4/10 for the right foot, with 0 for control. No pain-side effect was detected for any measurements in the pathological group ($p > 0.05$).

Postural control measurements

The results for postural control from ANOVA are presented in Table 3 for 5 balance conditions. Overall, the effects of interactions between groups and balance conditions were not significant ($p > 0.05$), except for variable mean frequency in M/L direction ($p < 0.01$), but with a weak ES $d = 0.10$. This last result was not expected because the difference observed was in favor of the control group with higher COP mean frequency values than the pathological group, mainly for BPEO (0.74 Hz vs. 0.50, respectively) and BPEC (0.78 vs. 0.57, respectively). However, group differences were observed mainly for area of COP ($p < 0.01$; $d = 0.08$) and COP velocity sway in A/P direction ($p = 0.022$; $d = 0.04$); which are the variables more sensitive to determine postural control deficits in a pathological group. Higher COP values for the pathological group indicated poorer postural control than healthy control (with low COP values) in all balance performance conditions (results illustrated in Figure 3).

Balance task conditions also varied significantly ($p < 0.01$; Table 3 for all COP parameters), where STEO, STEC, and UP produced more postural control challenges (higher COP values) than simple conditions (BPEO and BPEC) in both groups. Figure 3 illustrates these results for main COP parameters and sensitive effects of these conditions to discriminate between the two groups (pathological vs. control) mainly in STEC and UP.

At these two conditions (STEC and UP), pathological group (plantar fasciitis) reported more balance deficits than healthy-control mainly for Area COP variable (Figure 3A).

Walking measurements

The results for gait analysis from ANOVA are presented in Table 4 for three speed walking conditions. Again, the effects of interactions between groups and balance conditions were not significant ($p > 0.05$). Group-differences were observed mainly for velocity ($p < 0.01$; $d = 0.12$), step length ($p < 0.01$; $d = 0.16$) and step width ($p < 0.01$; $d = 0.18$) variables; where the pathological group (plantar fasciitis) reported lower values for these gait parameters as compared to healthy-control group across three speeds conditions, as illustrated also in Figure 4.

Walking speed conditions were significantly different between them ($p <0.01$; Table 4 for all walking parameters) as expected; where FS produced more walking challenges than simple conditions such as PF and RS. In fact, when the speed was increased, then velocity, step length, and step width have higher values than during slower walking. Figure 4 illustrates these results for the main parameters and the sensitive effects between the experimental conditions to discriminate differences between the two groups (pathological vs. control) on walking pattern.

Correlation between clinical foot measurements and postural control and gait

Tables 5 and 6 report the coefficient correlations between foot measurements and balance (COP area variable) and gait (velocity variable), respectively. No systematic significant correlations were found between these measurements. In Table 5, it was observed only a moderate significant correlation between the ROM of the 1st MTP of the right foot and the BPEC balance condition ($r= -0.58$), while in Table 6, a moderate significant correlation was found between PAP of the left foot and velocity during FS walking condition ($r =0.57$). All the other variables showed no or low correlation between them for the two tables presented.

DISCUSSION

This study aimed to compare participants with and without plantar fasciitis for the first time during five postural balance tasks under force platform and three speeds of walking activities under the gait analysis system, based on a technological measurement of biomechanics. Our hypothesis was confirmed. Plantar fasciitis compromises postural control mainly during challenge balance tasks and changes the walking patterns, especially during fast speed condition. Or, pathological group reported higher COP values under force platform measurements, while reporting lower gait values compared to the healthy-control group, suggesting that these individuals have an increased risk of falling based on poor balance and decreased velocity during walking. These new results have implications for clinical decision-making during preventive and rehabilitation programs for individuals with plantar fasciitis.

For balance measurements, the results of present study were better illustrated for the area ellipse of COP sway and COP velocity in the A/P direction of movement. These two variables proved to be more sensitive for postural instability in the pathological group, because their values were higher than the healthy control group, mainly in more challenging balance tasks (semi-tandem and unipodal). These results are supported by a previous study [29] and in agreement with Ağırman in a more recent study of 2018 [12], comparing 15 participants with fasciitis vs. 9 healthy across static and dynamic balance tasks on a system, namely Biodex balance. This system promotes a standardized and single balance protocol [12], which limit for some generalizations. However, Ağırman reported in their study that healthy-control group has better balance than the fasciitis group. From author, these results were explained by weakness of the plantar flexor muscles during balance performance [12]. In addition, another study that assessed 25 individuals with plantar fasciitis (mean age 52 years) and 25 healthy controls (mean age 49 years) during different balance tasks using a force platform, as the present study did, also reported poor balance for the experimental fasciitis group. The authors' explanation was that there is reduced elasticity around the fascia, which decreases proprioception and affects balance of the injured feet [13]. In addition, a decrease in postural control is often associated with an increased risk of falling in individuals with plantar fasciitis, when compared to healthy individuals as suggested by authors [13].

The originality of present study was that the balance tasks included are not systematic, such as the Biodex Balance system itself [12], and could better represent activities of daily living such as semi-tandem and unipodal conditions [19,27]. The unipodal condition is one of the most challenging and representative to assess postural control across adults and older individuals [19,27] and often a condition used to predict the risk of falls. This is the first study to report the results for these conditions in individuals with plantar fasciitis and further includes a gait analysis within the same experimental set-up in same study, as will be discussed later. It is essential to remember that the changes in postural control found in the present study are not related to the differences of age or BMI between our two groups. Effectively, age has an impact on postural control and the risk of falling due to neuro-musculoskeletal alteration, while decreasing physiological function [29]. Here, the use of an ANCOVA with age effect proved that it was not the cause of the differences between the two groups, despite our limited sample size. In addition, the two groups reported differences related to weight, but not for the BMI variable, which has been proven not to be related to changes in postural control measurements [30,31]. Thus, it could be assumed that modifications in postural control are caused in great part by the presence of a plantar fasciitis disorder and gradual alterations due to chronic pain (ex: proprioception deficit). In fact, these results may be explained by weakness of the plantar flexor muscles, a decrease in thickness of the plantar fascia or a reduced range of motion at the ankle (for example, the moderate correlation reported in the present study between the metatarsophalangeal joint and COP value), which are all factors that increase the pain related to plantar fasciitis, consequently affecting proprioception, balance, or gait performance as supported by the literature of issue [12,13,15,18].

Furthermore, the results of present study were supported in five balance tasks, including two more challenge conditions (semi-tandem and unipodal), which were sensitive enough to discriminate the two groups. These two challenge conditions increased the level of difficulty when compared to more simple tasks. This phenomenon was further supported for other studies that use a similar protocol, but comparing the postural balance in participants with and without chronic low back pain, older people, and Parkinson’s disease, for example [26,32,33]. Furthermore, the plantar fascia has a stability effect for the longitudinal medial arch of the foot during static stance and among patients with plantar fasciitis, and this capacity is diminished the higher the tension on the fascia [11]. This could explain why the pathological group has a poorer balance than the control group. In fact, the semi-tandem and unipodal conditions seem to be the ones that put more tension on the plantar fascia, which would explain why these are the two more challenging conditions.

With regard to gait analysis, this is the first study to compare subjects, with and without plantar fasciitis, during three speed-walking conditions. The present study results allowed us to conclude that plantar fasciitis modifies the walking pattern across different speeds. The pathological group showed a significant reduction in velocity, step length, and step width when compared to the control-group (as reported in Figure 4). These findings are in line with previous studies investigating walking in this population, which also reported a reduced step length for subjects with plantar fasciitis [34]. Only gait parameters was used rather than pressure variables, because the evidence supports that velocity and step length are the two main variables with strong correlations for functional balance tasks and risk of falling [35]. Effectively, it has already been shown that reduction in velocity and step length is strongly related to increased risk of falling, mainly in older people [36]. In addition, foot pain can cause reduced walking speed [37], which is associated to the results from present study when a moderate correlation was obtained between pain palpation and gait velocity ($r > 0.50$) during our analysis. This result is in relation with another study describing that patients with plantar fasciitis walk slower to avoid pain, leading to reduced cadence and velocity [38]. Moreover, it has been proven that modifications in gait performance are independent of gait speed in patients with plantar fasciitis [39], so the different walk speeds evaluated during our study do not impact the results. The fact that three different speeds was evaluated here allows us to have more data to validate if the same effect was observed for the three different speeds. The same pattern was observed for each speed, the plantar fasciitis group has a slower walk, so the other parameters were modified accordingly.

The results of present study show that adults with plantar fasciitis would be more prone to falls that non-pathological subjects, based on valid and reliable gait parameters [24]. For the differences reported between the three speed conditions, it was observed that during increased walking speed, in parallel, an increase in velocity, step length, and step width is observed. In fact, changes in walking speed caused a variation on gait parameters; for example, there is more variability in the walking pattern a faster speed, leading to an increased risk of falling [40]. These results were illustrated in neurological diseases like Parkinson’s [41] and other orthopaedic clinical conditions [42]. On the other hand, it has been reported that foot posture has an impact on plantar pressure, much like flat feet have a higher pressure peak on the medial aspect of the foot and cavus feet have a pressure peak more on the lateral column of the foot [43]. Specifically, people with plantar heel pain such as plantar fasciitis put more pressure on the forefoot than on the rearfoot, when walking [44] and present a modified kinematic for the rearfoot, the medial forefoot, the first metatarsal phalangeal joint due to the difference in ground reaction force with healthy individuals [45]. These results from posture and pressure responses are often associated with walking pattern changes, which supports the originality of our results, in agreement with other studies for different pathologies and protocols.

Based on the study results, a moderate correlation was found between ROM of the 1st MPJ of the right foot and COP value during bipodal with eyes closed (BPEC), as well as between PAP of the left foot and gait velocity parameters during fast speed (FS) under the gait analysis system. These correlations could be explained, in part, by the results from poor balance performance and a decreased gait performance when compared to healthy control. The correlation between ROM of 1st MPJ and COP agrees with the results of another study that found that a loss of ROM at the 1st MPJ can cause an increase of the area COP due to a poorer mechanism of control [18]. Another study found a link between plantar fasciitis and limited ROM at the 1st MPJ which caused increased tension to the plantar fascia [46] and the higher the tension on the plantar fascia, the lower the stability of the longitudinal arch of the foot. So, this correlation can explain why patients with plantar fasciitis have poorer balance. The correlation between PAP and reduced gait velocity are in relation with our previous findings of diminished walking speed among the pathological group, in an attempt to avoid pain [38] and the increased variability in gait parameters during high speed movements [40]. However, no systematic and significant correlations were found for other COP and gait parameters, which limits the conclusions for a relationship between clinical foot measurements and balance and gait, therefore limiting our study conclusions. No other study has evaluated the correlation between these clinical variables for patients with plantar fasciitis associated with COP measurements across five balance conditions, and/or gait analysis. In fact, previous studies have evaluated the correlations between foot posture and balance in a normal and aging population, reporting no significant correlation [47,48], which in part also concurs with the present study (no systematic effects in correlations).

In summary, our results have clinical and research implications for balance rehabilitation programs for individuals regarding the aging process, as well as for prevention programs linked to musculoskeletal foot postural disorders. Foot posture characteristics are of concern, since cutaneous plantar afferent activity plays a significant role in the regulation of postural control and gait [49]. If individuals with foot postural disorders receive less afferent input from the plantar cutaneous receptors, they may have less efficient mechanisms of control of their upright posture during a single-leg stance, for example, and possibly to execute an efficient walking performance [18]. However, our study has some limitations. First, there is some heterogenicity between the two groups regarding the age and weight of the participants. In addition, our power sample calculation was based on a previous study which also pointed out a limited lower sample size that may result in statistical errors (type 2 error), despite the sensitivity of the equipment (force platform or GaitRite) to discriminate balance and/or walking differences between groups. Muscular strength was not assessed between groups to evaluate if there is an impact on postural control and gait results. Also, the evaluation of the PAP was subjective and depended on the participants' pain tolerance, which may affect the results. The imagery could be useful to better determine the clinical status of the injured feet and the impact on balance and gait. From this work's perspective, it could be interesting to evaluate the effect of treatment such as plantar orthotics after some weeks of treatment, if it is possible to see an improvement in postural control and walking pattern. Adding these different elements to future work would allow a more specific evaluation of the impact of plantar fasciitis and the effect of one of its treatments to determine cause and effect through a longitudinal experimental design including a large sample and older people.

CONCLUSION

Individuals with plantar fasciitis reported poor postural control, mainly during more difficult balance tasks such as ST and UP than patients without this condition. These two balance-tasks were more sensitive to discriminate differences between them. In addition, gait parameters were affected by the pathology, where velocity, step length, and step width were in low values compared to healthy individuals. These results could suggest an increased risk of falls for individuals with plantar fasciitis. In addition, our findings have implications for clinicians during balance and gait evaluation and retraining to manage individuals with plantar fasciitis during rehabilitation programs and prevent falls.

Conflicts of Interest

The authors declare no potential conflicts of interest.

Author Disclosure Statement

There are no competing financial interests.

References

1. Natali AN, Pavan PG, Stecco C. A constitutive model for the mechanical characterization of the plantar fascia. Connect Tissue Res. 2010;51(5):337–46.

2. Park SY, Bang HS, Park DJ. Potential for foot dysfunction and plantar fasciitis according to the shape of the foot arch in young adults. J Exerc Rehabil. 2018;14(3):497–502.

3. Beeson P. Plantar fasciopathy: Revisiting the risk factors. Foot Ankle Surg. 2014;20(3):160–5.

4. Abate M, Schiavone C, Di Carlo L, Salini V. Achilles tendon and plantar fascia in recently diagnosed type II diabetes: Role of body mass index. Clin Rheumatol. 2012;31(7):1109–13.

5. Cunnane G, Brophy DP, Gibney RG, Fitzgerald O. Diagnosis and treatment of heel pain in chronic inflammatory arthritis using ultrasound. Semin Arthritis Rheum. 1996;25(6):383–9.

6. Monteagudo M, de Albornoz PM, Gutierrez B, Tabuenca J, álvarez I. Plantar fasciopathy: A current concepts review. EFORT Open Rev. 2018;3(8):485–93.

7. Petraglia F, Ramazzina I, Costantino C. Plantar Fasciitis in athletes: diagnostic and treatment strategies. A systematic review. 2017;7 (1)(Muscles, Ligaments and Tendons Journals):107–18.

8. Thompson J V., Saini SS, Reb CW, Daniel JN. Diagnosis and management of plantar fasciitis. Vol. 114, Journal of the American Osteopathic Association. American Osteopathic Association; 2014. p. 900–6.

9. Glazer JL. An approach to the diagnosis and treatment of plantar fasciitis. Phys Sportsmed. 2009;37(2):74–9.

10. Menz HB, Thomas MJ, Marshall M, Rathod-Mistry T, Hall A, Chesterton LS, et al. Coexistence of plantar calcaneal spurs and plantar fascial thickening in individuals with plantar heel pain. Rheumatol (United Kingdom). 2019;58(2):237–45.

11. Wearing SC, Smeathers JE, Urry SR, Hennig EM, Hills AP. The pathomechanics

of plantar fasciitis. Sport Med. 2006;36(7):585–611.

12. Ağırman M. Evaluation of balance and fall risk in patients with plantar fasciitis syndrome. SiSli Etfal Hastan Tip Bul / Med Bull Sisli Hosp. 2018;53(4):426–9.

13. Petrofsky J, Donatelli R, Laymon M, Lee H. Erratum: Petrofsky, J., et al. Greater Postural Sway and Tremor during Balance Tasks in Patients with Plantar Fasciitis Compared to Age-Matched Controls. Healthcare 2020, 8, 219. Healthcare. 2020;8(4):510.

14. Cheung JTM, Zhang M, An KN. Effect of Achilles tendon loading on plantar fascia tension in the standing foot. Clin Biomech. 2006;21(2):194–203.

15. Gonçalves GA, Kamonseki DH, Martinez BR, Nascimento MA, Lombardi Junior I, Yi LC. Static, dynamic balance and functional performance in subjects with and without plantar fasciitis. Fisioter em Mov. 2017;30(1):19–27.

16. Razeghi M, Batt ME. Foot type classification: a critical review of current methods. 2002;15:282–91.

17. Cho Y, Park JW, Nam K. The relationship between foot posture index and resting calcaneal stance position in elementary school students. Gait Posture. 2019;74(September):142–7.

18. Carvalho CE, da Silva RA, Gil AW, Oliveira MR, Nascimento JA, Pires-Oliveira DAA. Relationship between foot posture measurements and force platform parameters during two balance tasks in older and younger subjects. J Phys Ther Sci. 2015;27(3):705–10.

19. Da Silva RA, Bilodeau M, Parreira RB, Teixeira DC, Amorim CF. Age-related differences in time-limit performance and force platform-based balance measures during one-leg stance. J Electromyogr Kinesiol. 2013;23(3):634–9.

20. Kadri MA, Violette M, Dallaire M, de Oliveira FCL, Lavallière M, Ngomo S, et al. The immediate effect of two lumbar stabilization methods on postural control parameters and their reliability during two balance tasks. J Man Manip Ther. 2020;00(00):1–9.

21. Vieira ER, Lim HH, Brunt D, Hallal CZ, Kinsey L, Errington L, et al. Temporo-spatial gait parameters during street crossing conditions: A comparison between younger and older adults. Gait Posture. 2015;41(2):510–5.

22. Webster KE, Wittwer JE, Feller JA. Validity of the GAITRite® walkway system for the measurement of averaged and individual step parameters of gait. Gait Posture. 2005;22(4):317–21.

23. Bilney B, Morris M, Webster K. Concurrent related validity of GAITRite walkway system for quantification of the spatial and temporal parameters of gait. Gait Posture. 2003;17:68–74.

24. Vieira ER, Tappen R, Gropper SS, Severi MT, Engstrom G, De Oliveira MR, et al.

Changes on walking during street crossing situations and on dorsiflexion strength of older caribbean americans after an exercise program: A pilot study. J Aging Phys Act. 2017;25(4):525–32.

25. Menz HB, Latt MD, Tiedemann A, Kwan MMS, Lord SR. Reliability of the GAITRite® walkway system for the quantification of temporo-spatial parameters of gait in young and older people. Gait Posture. 2004;20(1):20–5.

26. de Oliveira MR, da Silva RA, Dascal JB, Teixeira DC. Effect of different types of exercise on postural balance in elderly women: A randomized controlled trial. Arch Gerontol Geriatr. 2014;59(3):506–14.

27. Oliveira MR, Vieira ER, Gil AWO, Fernandes KBP, Teixeira DC, Amorim CF, et al. One-legged stance sway of older adults with and without falls. PLoS One. 2018;13(9):1–9.

28. L.G. Portney MPW. Validity and Reliability; in Prentice-hall(Ed.): Foundations of Clinical Research Applications to Practice. 2n ed. Upper Saddle River, New Jersey; 2000.

29. Piirtola M, Era P. Force platform measurements as predictors of falls among older people - A review. Gerontology. 2006;52(1):1–16.

30. Jeong H, Wayne Johnson A, Brent Feland J, Petersen SR, Staten JM, Bruening DA. Added body mass alters plantar shear stresses, postural control, and gait kinetics: Implications for obesity. PLoS One. 2021;16(2 February):1–17.

31. Pereira C, da Silva RA, de Oliveira MR, Souza RDN, Borges RJ, Vieira ER. Effect of body mass index and fat mass on balance force platformeasurements during a one-legged stance in older adults. Aging Clin Exp Res. 2018;30(5):441–7.

32. da Silva RA, Vieira ER, Fernandes KBP, Andraus RA, Oliveira MR, Sturion LA, et al. People with chronic low back pain have poorer balance than controls in challenging tasks. Disabil Rehabil. 2018;40(11):1294–300.

33. Terra MB, Da Silva RA, Bueno MEB, Ferraz HB, Smaili SM. Center of pressure-based balance evaluation in individuals with Parkinson’s disease: a reliability study. Physiother Theory Pract. 2020;36(7):826–33.

34. Yoo SD, Kim HS, Lee JH, Yun DH, Kim DH, Chon J, et al. Biomechanical parameters in plantar fasciitis measured by gait analysis system with pressure sensor. Ann Rehabil Med. 2017;41(6):979–89.

35. Riis J, Byrgesen SM, Kragholm KH, Mørch MM, Melgaard D. Validity of the gaitrite walkway compared to functional balance tests for fall risk assessment in geriatric outpatients. Geriatr. 2020;5(4):1–7.

36. Vieira ER, da Silva RA, Severi MT, Barbosa AC, Amick BC, Zevallos JC, et al. Balance and gait of frail, pre-frail, and robust older hispanics. Geriatr. 2018;3(3):1–7.

37. Chaiwanichsiri D, Janchai S, Tantisiriwat N. Foot disorders and falls in older persons. Gerontology. 2009;55(3):296–302.

38. Thong-On S, Bovonsunthonchai S, Vachalathiti R, Intiravoranont W, Suwannarat S, Smith R. Effects of strengthening and stretching exercises on the temporospatial gait parameters in patients with plantar fasciitis: A randomized controlled trial. Ann Rehabil Med. 2019;43(6):662–76.

39. Brachman A, Sobota G, Marszałek W, Pawłowski M, Juras G, Bacik B. Plantar pressure distribution and spatiotemporal gait parameters after the radial shock wave therapy in patients with chronic plantar fasciitis. J Biomech. 2020;105:109773.

40. Brown KC, Hanson HM, Firmani F, Liu D, McAllister MM, Merali K, et al. Gait Speed and Variability for Usual Pace and Pedestrian Crossing Conditions in Older Adults Using the GAITRite Walkway. Gerontol Geriatr Med. 2015;1:233372141561885.

41. Nelson AJ, Zwick D, Brody S, Doran C, Pulver L, Rooz G, et al. The validity of the GaitRite and the functional ambulation performance scoring system in the analysis of Parkinson gait. NeuroRehabilitation. 2002;17(3):255–62.

42. Picouleau A, Orsoni N, Hardy J, Mabit C, Charissoux JL, Marcheix PS. Analysis of the effects of arthrodesis of the hallux metatarsophalangeal joint on gait cycle: results of a GAITRite® treadmill test. Int Orthop. 2020;44(10):2167–76.

43. Buldt AK, Allan JJ, Landorf KB, Menz HB. The relationship between foot posture and plantar pressure during walking in adults: A systematic review. Vol. 62, Gait and Posture. 2018.

44. Phillips A, McClinton S. Gait deviations associated with plantar heel pain: A systematic review. Clin Biomech. 2017;42:55–64.

45. Chang R, Rodrigues PA, Van Emmerik REA, Hamill J. Multi-segment foot kinematics and ground reaction forces during gait of individuals with plantar fasciitis. J Biomech. 2014;47(11):2571–7.

46. Aranda Y, Munuera P V. Plantar fasciitis and its relationship with Hallux limitus. J Am Podiatr Med Assoc. 2014;104(3):263–8.

47. Mohd Said A, Manaf H, Bukry SA, Justine M. Mobility and balance and their correlation with physiological factors in elderly with different foot postures. Biomed Res Int. 2015;2015.

48. Cote KP, Brunet ME, Gansneder BM, Shultz SJ. Effects of pronated and supinated foot postures on static and dynamic postural stability. J Athl Train. 2005;40(1):41–6.

49. Maki BE, Perry SD, Nome RG, McIlroy WE. Effect of facilitation of sensation from plantar foot-surface boundaries on postural stabilization in young and older adults. Journals Gerontol - Ser A Biol Sci Med Sci. 1999;54(6):281–7.

Table 1. Participants' characteristics

Variables	**Control Group (n=15)**	**Pathological Group (n=15)**	***P* value**
Age	33.3 ± 13.8	50.1 ± 10.5	<0.001*
Height	1.7 ± 0.1	1.7 ± 0.1	0.887
Weight	76.4± 14.1	90 ± 19.1	0.035*
BMI	26.9 ± 4.9	31.5 ± 7.2	0.051

Data are expressed as mean ± SD (standard derivation).

BMI = body mass index.

* Significant group difference $p < 0.05$ (Student's *t*-test)

Table 2. Biomechanical measurements of foot

Variables	**Control group (n=15)**	**Pathological group (n=15)**	***P* value (group)**	***P* value (Effect side)**	***P* value (interaction)**
PAP (L)	0 ± 0	2.9 ± 2.5	<0.001*	0.498	0.498
PAP (R)	0 ± 0	3.7 ± 3.8			
NCP (L)	3.5 ± 2.6	3.0 ± 1.5	0.08	0.537	0.952
NCP(R)	3.8 ± 2.5	2.6 ± 1.8			
Arch height (L)	4.2 ± 0.6	4.5 ± 0.7	0.126	0.905	0.553
Arch height (R)	4.3 ± 0.6	4.6 ± 0.8			
ROM 1stMPJ (R)	44.3 ± 6.9	41.7 ± 9.9			
ROM ankle (R)	4.9 ± 2.8	4.7 ± 4.5			

All data are express as mean ± SD (standard derivation).
(L) = left. (R) = right. PAP = pain at palpation. NCP = neutral calcaneal position. ROM = range of motion. MPJ = metatarsophalangeal joint
* Significant group difference = $p < 0.05$ (Student’s *t*-test)

Table 3. Postural control measurement: ANOVA results

Variables	**Two-way ANOVA results (*P* values)**			**Direction of effects** [a]
	Groups (effect size)	**Conditions (effect size)**	**Groups X Conditions (effect size)**	
Aera CoP	<0.01 (0.08) *	<0.01(0.62) *	0.38 (0.03)	BPEO and BPEC < STEO, STEC and UP
Velocity A/P	0.02 (0.04) *	<0.01 (0.68) *	0.81 (0.01)	
Velocity M/L	0.13 (0.02)	<0.01 (0.78) *	0.24 (0.03)	
Frequency A/P	0.06 (0.02)	<0.01 (0.49) *	0.35 (0.03)	
Frequency M/L	<0.01 (0.08) *	<0.01 (0.51) *	<0.01 (0.10) *	

ANOVA results (*P* value) corresponding to the comparisons between the control group and pathological group (group factor) and between balance conditions (conditions factor) for the postural control measurement

* Significant differences between group (control vs. pathological) and between conditions (BPEO vs. BPEC vs. STEO vs. STEC vs. UP)

[a] Directions of the effects when the conditions factor was significant. BPEO and BPEC show less instability than STEO, STEC and UP.

Table 4. Walking measurement from gait analysis: ANOVA results

Variables	**Two-way ANOVA results (*P* values)**			**Direction of effects** [a]
	Groups (effect size)	**Conditions (effect size)**	**Groups X Conditions (effect size)**	
Velocity	<0.01 (0.12) *	<0.01(0.86) *	0.15 (0.04)	RS < PS < FS
Cadence	0.41 (0.01)	<0.01 (0.81) *	0.72 (0.01)	
Step length	<0.01 (0.16) *	<0.01 (0.74) *	0.67 (0.01)	
Step width	<0.01 (0.18) *	<0.01 (0.74) *	0.59 (0.01)	

ANOVA results (*P* value) corresponding to the comparisons between the control group and pathological group (group factor) and between balance conditions (conditions factor) for the walking measurement with GAITRite system.

* Significant differences between group (control vs. pathological) and between conditions (PS = Preferred Speed, RS = Reduced Speed, FS = Fast speed.)

[a] Directions of the effects when the conditions factor was significant. RS show diminished walk parameters compared to PS and FS.

Table 5. Coefficient correlation results for COP area parameter from balance

Variables	BPEO	BPEC	STEO	STEC	UP
PAP (L)	0.41	-0.08	0.09	0.20	0.17
PAP (R)	0.16	0.19	0.06	0.30	-0.05
NCP (L)	0.39	0.11	-0.05	0.20	0.22
NCP (R)	0.47	0.20	0.10	0.25	0.21
Arch height (L)	0.07	0.03	-0.43	0.02	0.35
Arch height (R)	-0.03	-0.09	-0.47	0.06	0.24
ROM 1st MPJ (L)	-0.05	-0.43	-0.29	-0.68	-0.36
ROM 1st MPJ (R)	-0.02	-0.58*	-0.20	-0.43	-0.16
ROM ankle (L)	0.49	0.07	-0.16	-0.16	-0.12
ROM ankle (R)	0.41	0.03	-0.17	-0.13	-0.15

(L) = left. (R) = right. PAP = pain at palpation. NCP = neutral calcaneal position. ROM = range of motion. MPJ = metatarsophalangeal joint. BPEO = Bipodal eyes open. BPEC = Bipodal eyes close. STEO = Semi-tandem eyes open. STEC = Semi-tandem eyes closed. UP = Unipedal.

Table 6. Coefficient of correlation results for gait analysis

Variables	PS	RS	FS
PAP (L)	0.25	-0.02	0.57*
PAP (R)	0.01	0.25	-0.02
NCP (L)	-0.47	-0.19	-0.08
NCP (R)	-0.43	-0.32	-0.11
Arch height (L)	0.12	0.38	0.38
Arch height (R)	0.17	0.46	0.36
ROM 1st MPJ (L)	-0.18	0.19	-0.01
ROM 1st MPJ (R)	-0.03	0.26	0.03
ROM ankle (L)	0.22	0.06	0.36
ROM ankle (R)	0.23	0.05	0.36

(L) = left. (R) = right. PAP = pain at palpation. NCP = neutral calcaneal position. ROM = range of motion. MPJ = metatarsophalangeal joint. PS = Preferred Speed. RS = Reduced Speed. FS = Fast speed.

(Figure 1)

Figure 1. Clinical measurements of foot**:** A) Arch height, B) Neutral position of the calcaneum, C) ROM of 1st metatarsophalangeal joint and D) ROM of ankle joint.

(Figure 2)

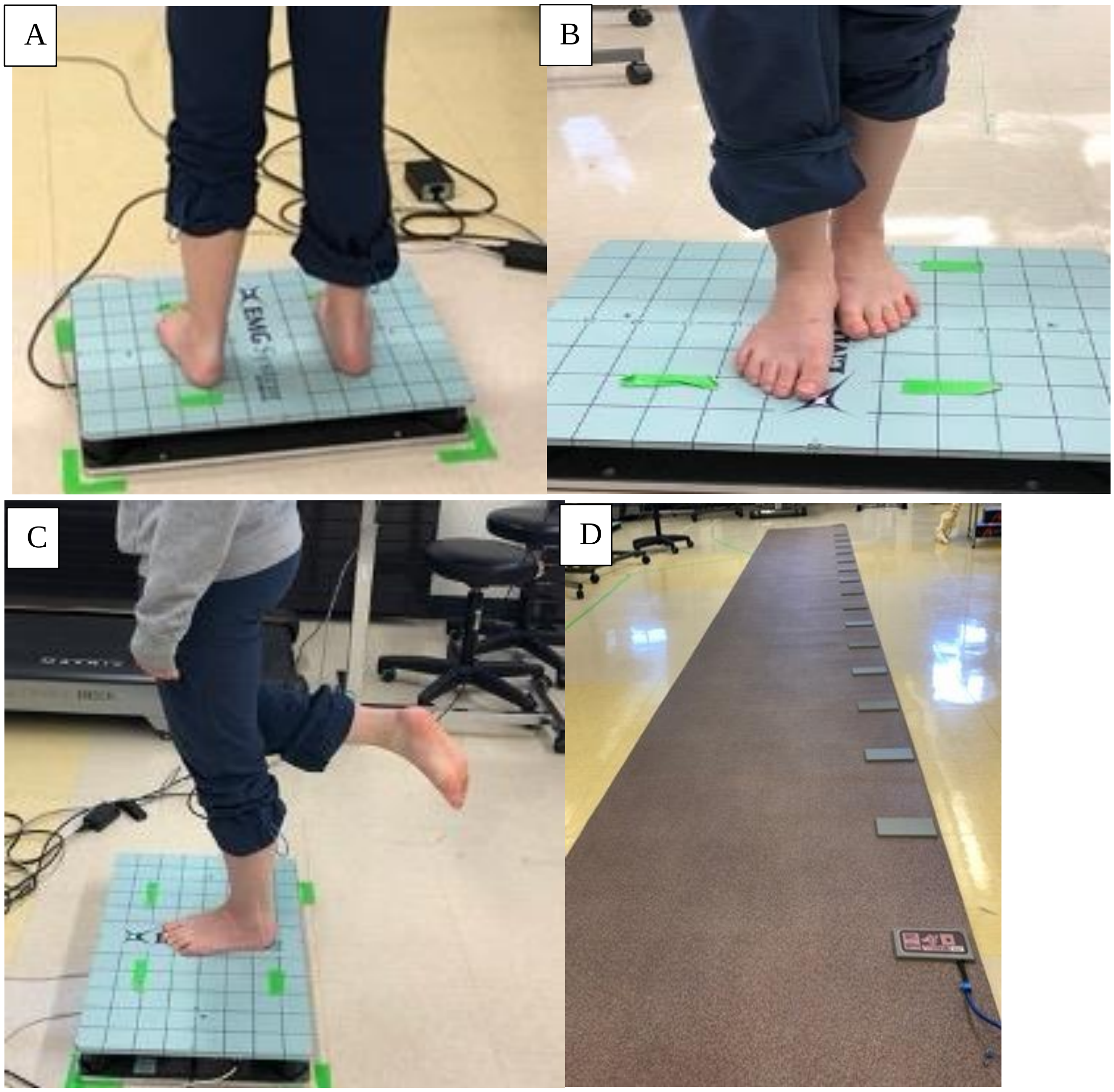
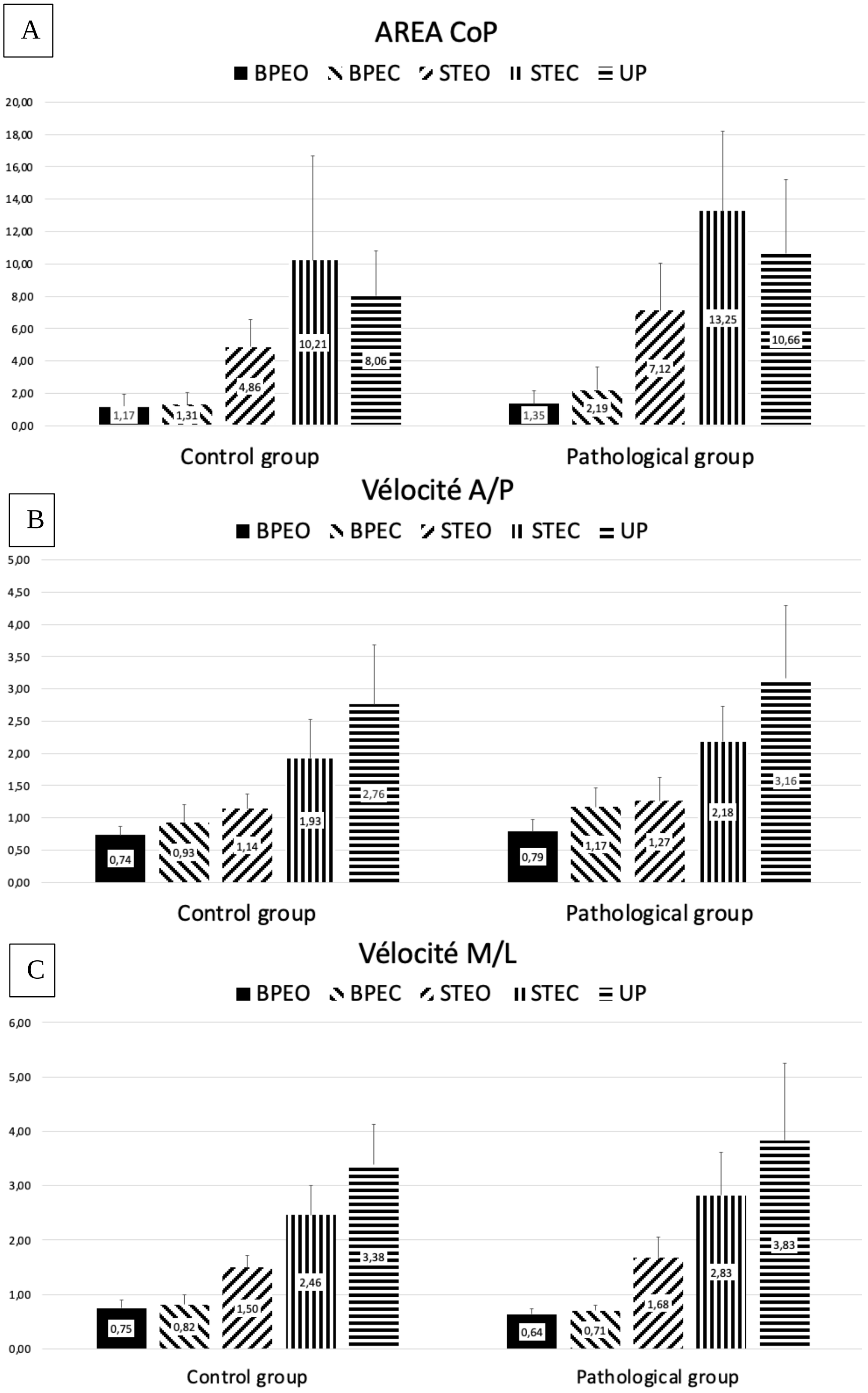


Figure 2. Force Platform and GAITRite system: A) Bipodal position, B) Semi-tandem position and C) Unipodal position on a force platform (BIOMEC400). D) GaitRite system for walking analysis across three speeds.

(Figure 3)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BPEO
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1,31
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Control group
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Vélocité A/P
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BPEC
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Control group
Pathological group
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Control group
Pathological group

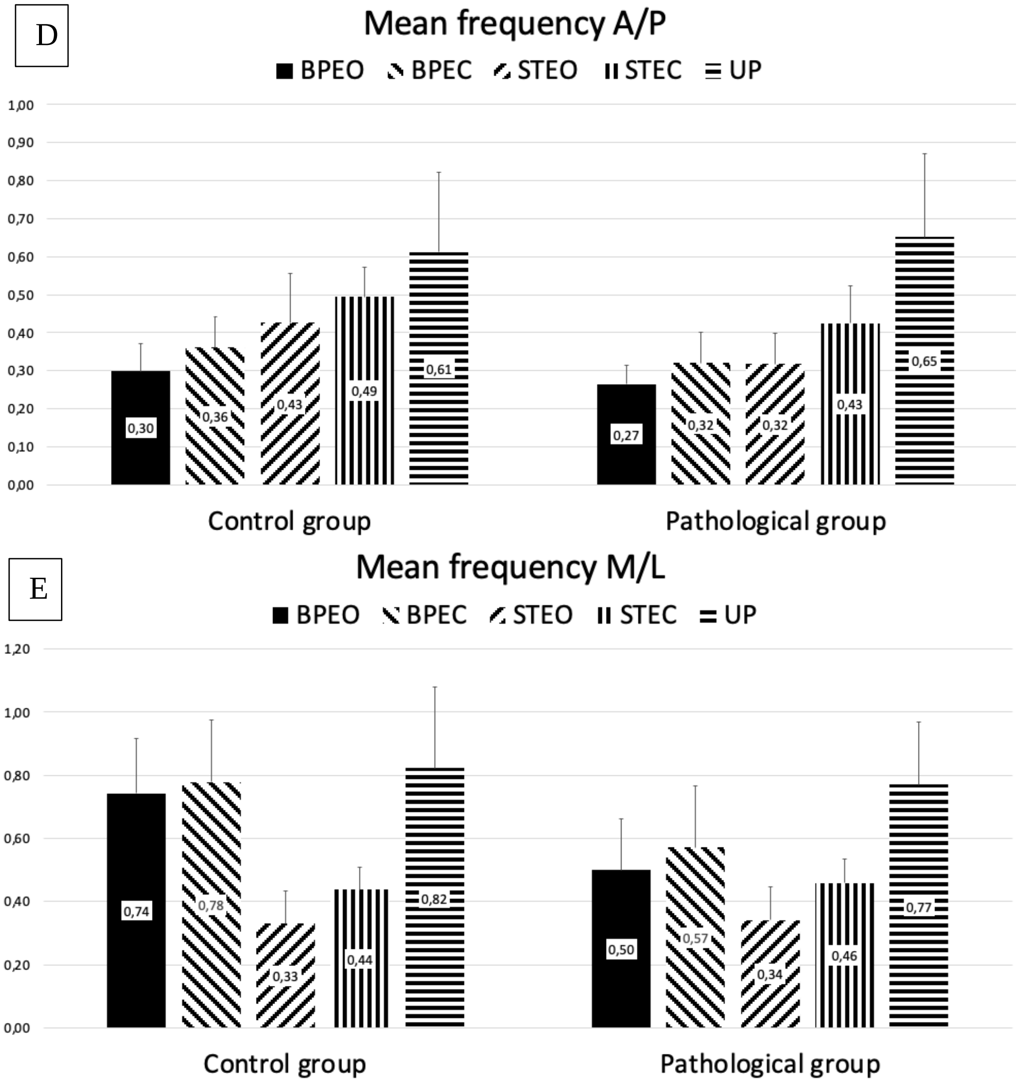

Figure 3. Postural control results from force platform between groups and conditions for: Area of COP (A); COP velocity sway in A/P (B) and in M/L (C), and mean frequency in A/P (D) and in M/L directions (E). Data are from mean values and error bars correspond to standard deviations.

(Figure 4)

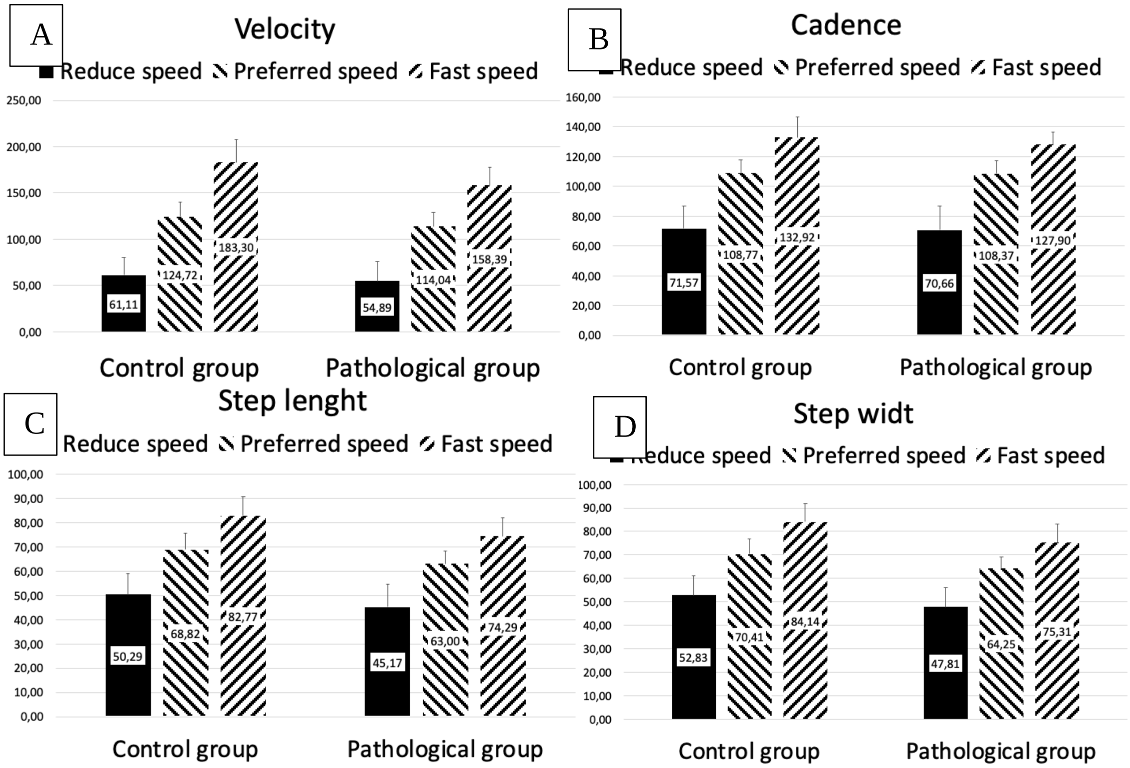

Figure 4. Walking results from GAITRite system. Groups and speed comparisons. The gait parameters are: velocity (A), cadence (B), step length (C) and step width (D). Data are from mean values and error bars correspond to standard deviations.