Gender-Related Gait Pattern Differences in Sagittal Plane: Study in Healthy Middle Aged Adults

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Abstract

The computational gait analysis was expected to reveal differences in gait parameters between the two genders. The aim of this study was to investigate the existence of sex-related differences in gait patterns in healthy Syrian middle aged adults when they walked at their normal speed. Fourteen healthy middle aged adults (8 females, 6 males) aged 35 to 55 years volunteered to complete this study. Spatio-temporal parameters and sagittal kinematic and kinetic data were obtained and analyzed using six cameras Smart-D optoelectronic motion capture system (BTS, Milan, Italy), and two force plates (Kistler,Switzerland) in biomechanical laboratory in Bioengineering department, Faculty of mechanical and Electrical Engineering at Damascus university. The statistical study was conducted using the SPSS statistical program. The results showed that the females had significantly 23% slower gait speed, 21% shorter stride length, 21% narrower step width. They walked with significantly more anteriorly pelvic tilt throughout whole gait cycle, 26% greater hip joint flexion at opposite toe-off event, 11% less hip joint extension at heel rise event, 32% greater Mean hip flexion during the whole swing phase, 3% greater ankle plantarflexion pre swing, and 30% smaller ankle dorsiflexion moment. There were significant differences in hip and ankle range of motion (ROM) between the two sexes. These sex differences in gait patterns indicate the importance of taking sex into account when interpreting and treating pathological gait as well as when developing reference gait parameters databases.

Key words: Male, Female, Gait analysis, Spatio-temporal parameters, Kinematics, Kinetics.

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الاختلاف المرتبط بالجنس لنمط المشية في المستوى السهمي:
دراسة على البالغين الأصحاء

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الملخص

من المتوقع أن يكشف تحليل المشي المحوسب عن اختلافات في محددات المشي بين الجنسين. الهدف من هذه الدراسة هو التحقق من وجود اختلافات مرتبطة بالجنس في أنماط المشي لدى البالغين السوريين الأصحاء عندما يمشون بسرعتهم الاعتيادية. تطوع لإتمام هذه الدراسة 14 شاباً وشابة بصحة جيدة (8 نساء، 6 ذكور) تتراوح أعمارهم بين 35 و55 عاماً. تم الحصول على محددات المسافة والزمن وعلى المحددات الحركية والتحريكية في المستوي السهمي وتحليلها باستخدام نظام التقاط حركة كهرضوئي مكون من ست كاميرات من شركة (BTS) الإيطالية وصفيحتي قوى من نوع كيستلر، وذلك في مخبر الميكانيك الحيوي، قسم الهندسة الطبية، كلية الهندسة الميكانيكية والكهربائية في جامعة دمشق. أجريت الدراسة الإحصائية باستخدام برنامج SPSS الإحصائي. أظهرت النتائج أنه للإناث سرعة مشي أبطأ بنسبة (23%)، طول دورة مشي أقصر (21%)، وعرض خطوة أضيق (21%) مقارنة مع الذكور. وتميزت المشية لدى الإناث بإمالة أمامية أكبر للحوض خلال كامل دورة المشي، قبض ورك أكبر (26%) عند مغادرة أصابع القدم الأخرى للأرض، بسط ورك أقل (11%) عند رفع عقب القدم عن الأرض، قبض ورك أكبر (32%) لمتوسط القيم خلال طور التأرجح، (3%) بسط أكبر لمفصل الكاحل قبيل التأرجح، وعزم أصغر لقبض الكاحل (30%). كانت هناك فروق ذات معنى احصائي في مجال حركة مفصلي الورك والكاحل بين الجنسين. تشير هذه الفروق بين الجنسين في أنماط المشي إلى أهمية أخذ الجنس بعين الاعتبار عند تفسير وعلاج المشية المرضية وكذلك عند تطوير قواعد بيانات مرجعية لمحددات المشي.

الكلمات المفتاحية: ذكور، إناث، تحليل المشي، محددات المسافة والزمن، المحددات الحركية، المحددات التحريكية.

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1. Introduction

There are many physical differences between men and women, the most important of which is the difference in the formation of bones, this difference is clear in the shape of the skeleton between men and women, for example, "Men often have longer legs than women's". Women are often shorter than men while they have wider pelvic and torso compared to men [8,14]. Moreover, adult men and women differ markedly in muscular composition, it is noticeable that men have greater muscle strength and less fat mass compared to women [17]. So it is also likely that gait patterns will differ between the two sexes.

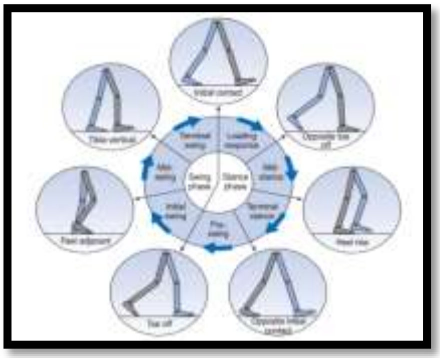

Fig. (1). Positions of the legs during a single gait cycle [20].

For example, two studies assessed torso sway gender differences [3,11], there was no difference between males and females. Oberg and colleagues found significant differences in the spatio-temporal parameters and kinematic parameters while walking [15,16]. Yamasaki and colleagues found that the spatio-temporal parameters at a given speed were significantly greater in females than in males [21]. Previous investigations have also determined gender differences in joints motion exist during walking [10,12]. Also, The effect of gender on lower limb kinematics has already been reported by several studies [4,13]. In particular, Chehab et al [4] reported an increased hip flexion in women, but only at the maximum flexion during swing. Asai et al [1] observed that the pelvic tilt was shown statistically higher in women on lateral standing. Thus, Because of the conflict of some studies in the presence or absence of a difference in the gait pattern between males and females, as well as because of the limited studies in literature that study the analysis of gait on the middle aged group and the impact of other factors, such as gender, on it, as most of the studies were dealing with the elderly, there is still a need to identify gender differences in gait parameters, confirm observations, and seek additional explanations for the reasons for these differences. The purpose of this study was to evaluate gender differences in gait patterns in healthy Syrian middle aged adults when they walked at their normal speed.

2. Theoretical basics

The human walking can be defined as 'a locomotion involving the use of the two legs, alternately, to provide both support and propulsion. The gait cycle is the time period in which one foot contacts the ground to when that same foot again contacts the ground. The following terms are used to identify major events during the gait cycle, **Figure.1**: (Initial contact, Opposite toe off, Heel rise, Opposite initial contact, Toe off, Feet adjacent, Tibia vertical). These seven events subdivide the gait cycle into seven periods, four of which (Loading response, Mid-stance, Terminal stance, Pre-swing) occur in the stance phase, when the foot is on the ground, and three

(Initial swing, Mid-swing, Terminal swing) occur in the swing phase, when the foot is moving forward through the air [20].

Gait is generally described by a number of parameters called spatio-temporal parameters, These Parameters are:

1. **Cycle duration:** the time which is taken to achieve one gait cycle.
2. **Stance phase duration:** the period between initial contact and toe off of the foot.
3. **Swing phase duration:** the period between toe off and second initial contact of the foot.
4. **Double support duration:** the period when both feet are on the ground.
5. **Stride length:** the distance between two successive placements of the same foot.
6. **Step length:** the distance along the walking line between two successive initial contacts.
7. **Step width:** the distance between the right and left heels when both are at the same event.
8. **Speed of walking:** the distance covered by the body in a given time.
9. **Cadence:** the number of steps taken in a given time.

The terms kinetics and kinematics are commonly used in gait analysis. Kinetics is the study of forces and moments but without any detailed knowledge of the position, orientation, velocity, or acceleration of the objects involved. Kinematics describes motion, but without reference to the forces involved. It is important to mention that all of the kinematics are measured with respect of the individual joint angle position during standing as a reference point when calculating human body angles using motion capture system for gait analysis [20].

3. Methods

3.1. Subjects

Fourteen healthy volunteers (8 females and 6 males) agreed to participate in this study, they included in the adult group (aged from 35 to 55 years), subjects with any degenerative changes were excluded. The purpose of the study was explained to each subject, and his / her human right was protected.

3.2. Anthropometric data

First of all the mass [kg] and the height [cm] of each subject were evaluated, then the other anthropometrical parameters were measured: Asis breadth, Pelvic depth, leg length, knee diameter, malleolus width.

3.3. Motion measure and Expermental procedure.

Six cameras Smart-D optoelectronic motion capture system (BTS, Milan, Italy) acquiring at 200 Hz, and two force plates (Kistler,Switzerland) at 200 Hz were used to measure 3D kinematics and reaction forces (GRF_s) respectively. Twenty - two retroreflective markers (twenty of these markers are spherical, while the remaining two are hemispherical) positioned to the following prominent bony landmarks, according to a modified Davis Heel protocol for studying lower limb, pelvis, and trunk [7], as shown in **Figure.2**:

Bilaterally over the acromion, the 7th cervical vertebra (C_7), two pelvic markers on both anterior superior iliac spines, sacral marker on the midpoint of the line connecting the two posterior superior iliac spines, bilaterally on great trochanter, bilaterally on lateral femoral condyle, bilaterally on fibula head, bilateral ankle markers on the lateral malleolus, bilateral forefoot markers on the 5th metatarsal head, bilaterally on heel, one marker on each thigh attached on rigid bar and placed at nearly 1/3 of the length of femur, one marker on each shank attached on rigid bar and placed at nearly 1/3 of the leg segment[18].

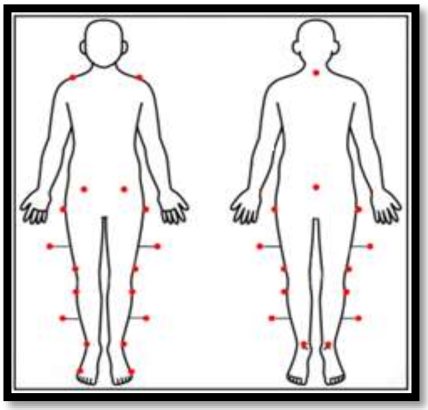

Fig. (2). Davis Heel davis protocol for marker placement [18].

After the placement of markers, and anthropometric measurements were taken for each subject, the acquisition phase started and the subject asked to perform two different tasks:

- Standing on a platform and holding an orthostatic position for 5 seconds, in this task the subject asked to align his/her feet in order to avoid having one foot in a more anterior or posterior position with respect to the other.
- Walking barefoot normally across the working volume defined during the calibration phase of the optoelectronic system.

Each subject performed three Successful trials, Then the average of these three trials was taken. For each acquisition, markers trajectories were reconstructed automatically using frame-by-frame tracking software. **Figure.3** shows the markers position during subject standing .

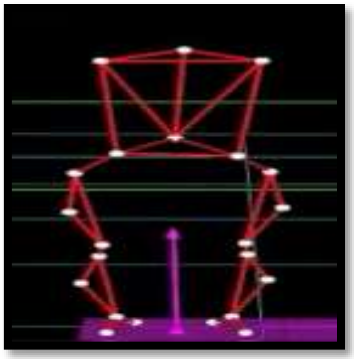

Fig.(3). markers position during subject standing [18].

3.4. Normalization and data analysis.

Before the comparison of gait analysis data, a data normalization was done to remove the effect of body size [9]. All kinetic data were divided by body weight and height, and the ground reaction force was divided by body weight. All the gait data were analyzed using SPSS statistical software. Gender difference was tested with independent t-test, and ANCOVA. The ANCOVA with height as the covariate, and sex as the fixed factor was practiced for leg length, speed, stride length, and step width. Statistical significance was defined if P-value was less than 0.05.

4. Results

4.1. Anthropometric data

The characteristics of the study subjects and the statistics for age, height, mass, and anthropometric data are presented in **table.1**. The females participants were significantly shorter ($p = 0.002$) and weighted less ($p = 0.008$), but there was no significant difference in age ($p = 0.57$) compared to the males. Women's physique is characterized by larger asis breadth and shorter leg length ($P<0.05$), but the Ancova with height as the covariate showed that the leg length isn't a gender feature.

Table. (1): Statistics for age, height, and mass of the study subjects. (*) Statistically significant difference.

Variable	Mean (SD)		P-Value
	Males (N=6)	Females (N=8)	
Age (year)	43 (8.87)	40.16 (7.98)	0.57
Height (cm)	168.6 (5.65)	155.4 (5.31)	0.002*
Mass (kg)	77.5 (13.14)	56.83 (7.98)	0.008*
Leg Length (cm)	93.5 (1.7)	83 (2.1)	0.0003*
Ancova	0.302		0.65
Asis Breadth (cm)	24.5 (3.1)	26.2 (2.1)	0.032*
Pelvic depth (cm)	6 (1.11)	6.1 (1.01)	0.87
Knee diameter (cm)	8.3 (0.91)	8 (0.83)	0.64
Malleolus width (cm)	6.7 (0.36)	6.5 (0.33)	0.57

4.2. Spatiotemporal data

The comparison in gait spatio-temporal parameters between males and females in regard to the mean values are shown in **table. 2**.

Females had a significantly less gait cycle duration. shorter stride length and narrower step width ($p=0.036$, 0.015, 0.046, respectively), but higher cadence and step length ($p=0.037$, 0.032). However, the females gait speed was significantly slower than males ($p = 0.04$), but when the Ancova test was practiced with height as the covariate, it was found that the speed difference could not be a gender feature. There was no significant difference between the men and women in the duration of the stance phase and the double support time ($p > 0.05$).

Table. (2): Comparison of gait parameters between males and females. ((%GC): percent of gait cycle. (%height/s): percent of height/second).
(*) Statistically significant difference.

Spatio-temporal gait para-meters	Mean (SD)		P-Value
	Males (N=6)	Females (N=8)	
Gait cycle duration (s)	1.14 (0.06)	1.11 (0.07)	0.036*
Stride length (m)	1.38 (0.18)	1.09 (0.17)	0.015*
Ancova	4.67		0.021*
Step width (m)	0.19 (0.03)	0.15 (0.01)	0.046*
Ancova	11.4		0.016*
Step length (m)	0.61 (0.04)	0.64 (0.03)	0.032*
Stance duration (% GC)	60.18 (1.55)	58.84 (6.7)	0.64
Double support duration (% GC)	11.29 (2.04)	11.27 (1.7)	0.98
Gait speed (%height/s)	68.75 (14.39)	53.05 (8.18)	0.04*
Ancova	2.77		0.057
Cadence (step/min)	99.62 (7.9)	127.3 (2.7)	0.037*

4.3. Kinematic and kinetic data

Mean peak values for all kinematic values are listed in table.3, and Mean peak values for all kinetic values and vertical ground reaction force are listed in table.4. All the data for each joint averaged for all males and females over a full gait cycle. Statistically significantly different peak values are listed with an asterisk (*). **Figure.4** shows vertical ground reaction force, kinematics and kinetics for males and females. Visual inspection of the graphs shows that there are similar basic patterns between males and females, although there are some differences in the average peak values. The second peak of vertical ground reaction force was smaller for women compared to men. With respect to kinematic parameters The angular motion of the pelvic in sagittal plane is compared between the two sex groups, the pelvic tilt was significantly more posteriorly in males, ($p < 0.05$), throughout whole gait cycle. There was a significant difference between the two sexes in hip joint kinematic in sagittal plane through the whole gait cycle ($p < 0.05$), the females had (26%) greater hip flexion at opposite toe-off event, (11%) less hip extension at heel rise event, and (32%) greater Mean hip flexion during the whole swing phase, than males. There are no significant differences for the hip kinetic in this plane. In this study the results didn't show any significant differences between males and females in the kinematics and kinetics of the knee joint. In sagittal plane, the ankle plantarflexion was significantly(3%) greater in women at toe-off point, and the ankle dorsiflexion moment was significantly smaller compared with males' ($p<0.05$) during push-off, while There are no other statistically significant differences for the ankle in this plane.

Table. (3): Kinematic values. (*) Statistically significant difference.

Peak values of kinematics (deg)	Mean (SD)		P-Value
	Males (N=6)	Females (N=8)	
Pelvic tilt (opposite toe-off)	10.3	12.8	0.00001*
Pelvic tilt (opposite initial contact)	11.9	13.2	0.015*
Hip flexion (opposite toe-off) ①	31.4 (4.1)	39.6 (4.7)	0.012 *
Hip extension (Heel rise) ②	-14.7(3.9)	-1.9 (5.1)	0.036 *
Hip flexion (Mean value during swing phase) ③	29.7 (3.6)	39.1 (2.7)	0.028*
Knee flexion (opposite heel rise) ①	25.3 (2.7)	26.3 (1.8)	0.124
Knee extension (heel rise) ②	18.6 (1.4)	19.5 (1.6)	0.201
Knee flexion (swing phase) ③	68.1 (2.1)	70.4 (1.3)	0.537
Ankle plantar flexion ①	-3.1 (4.3)	-3 (3.7)	0.893
Ankle dorsi-flexion (Heel rise) ②	14.8 (6.0)	16 (4.4)	0.613
Ankle plantar flexion (toe-off) ③	-19.1 (1.3)	-19.6 (2.5)	0.041*
Ankle dorsi-flexion (middle swing phase) ④	7.1 (3.2)	6 (4.5)	0.577

Table.(4): Kinetic values and vertical ground reaction force. (*) Statistically significant difference.

Peak values of parametres	Mean (SD)		P-Value
	Males (N=6)	Females (N=8)	
Kinetics (N.m/Kg.m)			
Hip flexion moment (after initial contact) ①	0.42 (0.08)	0.45 (0.11)	0.930
Hip extension moment (opposite Initial contact) ②	-0.58 (0.15)	-0.61 (0.19)	0.200
Hip flexion moment (end of swing phase) ③	0.02 (0.05)	0.05 (0.10)	0.328
Knee extension moment (Initial contact) ①	-0.14 (0.34)	-0.15 (0.30)	0.238
Knee flexion moment (opposite toe-off) ②	0.35 (0.09)	0.35 (0.11)	0.196
Knee extension moment (heel rise) ③	-0.03 (0.41)	-0.03 (0.32)	0.126
Knee flexion moment (before toe-off) ④	0.16 (0.20)	0.16 (0.46)	0.417
Ankle plantar - flexion ①	-0.137(0.12)	-0.14 (0.18)	0.610
Ankle dorsi – flexion (after opposite initial contact) ②	0.64 (0.07)	0.58 (0.05)	0.010*
Vertical ground reaction force (N/kg)			
First peak force	1.12 (0.91)	1.09 (0.80)	0.611
Minimum force	0.84 (1.1)	0.86 (0.95)	0.569
Second peak force	1.06 (0.75)	0.97 (0.88)	0.034*

Range of motion (ROM) for the lower joints in sagittal plane are presented in **table. 5.**

Females walked with less hip ROM (p =0.016) and greater ankle ROM (p=0.003) compared to males, but there was no significant difference in knee ROM ($P>0.05$).

Table.(5): Range of motion for lower joints in sagittal plane. (*) Statistically significant difference.

Range of motion (deg)	Mean (SD)		P-Value
	Males (N=6)	Females (N=8)	
Hip	46.2 (15.1)	41.3 (16.7)	0.016*
Knee	57.1 (4.16)	59.4 (4.71)	0.669
Ankle	33.9 (2.03)	35.6 (3.1)	0.003*

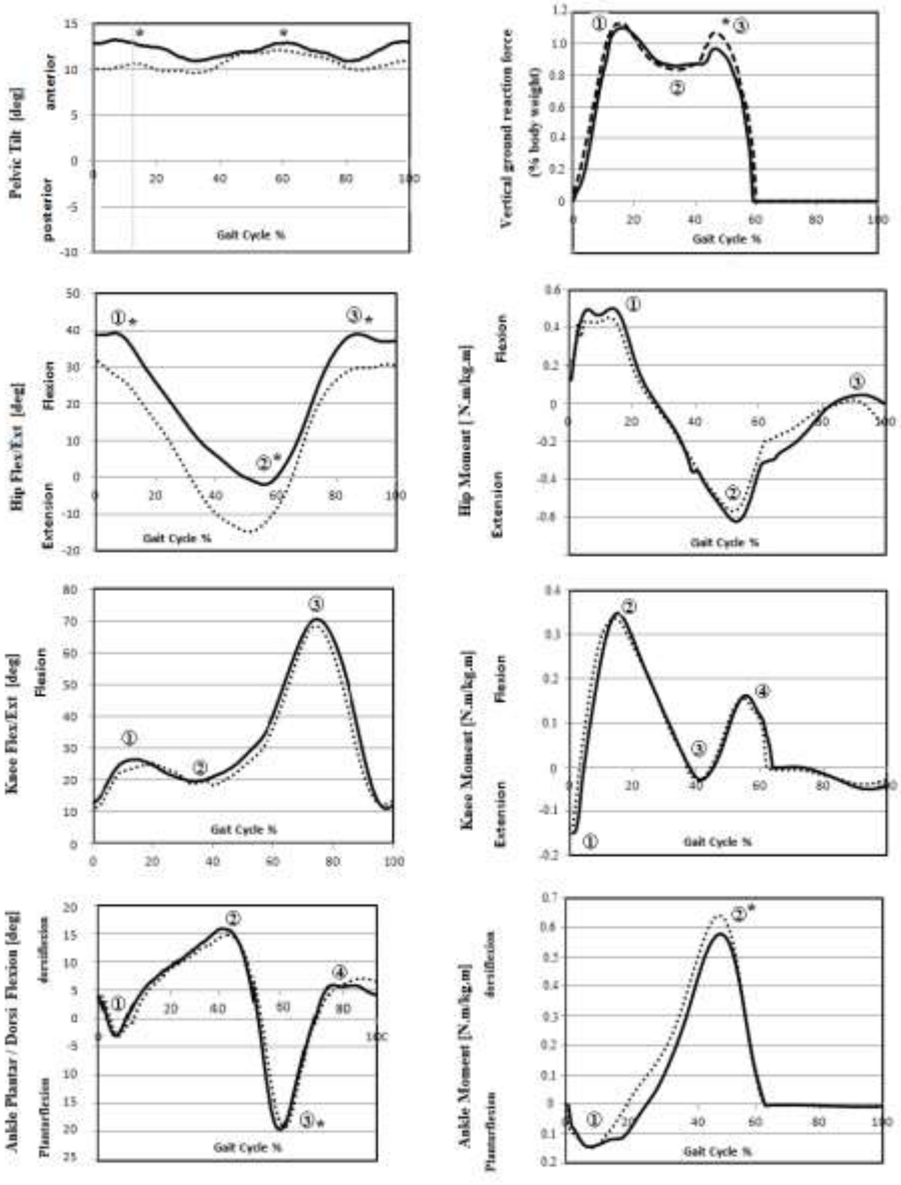

Fig. (4). Male and Female vertical ground reaction force, kinematics and kinetics in sagittal plane. Solid lines represent females, doted lines represent males. Each curve represents the average sex-specific curves. (*) Statistically significant difference.

5. Discussion

In this study, the gender effects on spatiotemporal gait parameters, kinematics, and kinetics of the lower extremity joints were investigated using three-dimentional gait analysis, it was done in sagittal plane among (14) healthy middle aged adults who walked at self-selected speed.

The females physique was significantly greater for asis breadth and smaller for leg length ($p<0.05$), However, it appeared that shorter leg length in females was not considered a sexual characteristic of female gait when the Ancova test was performed. Also, the results showed that women take more cadence with shorter stride length and narrower step width than men. Considering the female pelvis, which was wider than the males, these parameters seem to be influenced by the physical size, as there are many structural and sexual differences between their pelvis. Although there is a difference in walking speed between the sexes, which was lower in females, but this could not be a gender feature as shown by the Ancova test. The results of this study in the gender differences in spatiotemporal parameters are consistent with most of the Cho's results [5], while there are partially consistent with Kerrigan's [12], and there was no consistent with Bruening's [2]. In Cho's report, females had significantly shorter stride length and step width, slower speed but no gender differences found when it normalized with leg length, similar duration of stance phase and double support period, and cadence as great as male's [5]. In Kerrigan's report, the spatiotemporal data showed a few significant differences: greater cadence and longer stride length in females, but there was no significant difference in speed [12]. These results can emphasize that in Kerrigan's study the females do extra effort to increase their stride length to walk as speed as men's, which do not exist in this study. In Bruening's report, there was noticeable but not significant differences in speed, stride length, and cadence When accounting for body size [2]. In sagittal plane, there were significant increase in female hip flexion through whole gait cycle due to increase of step length, and decrease in hip extension pre swing which found to compensate the increase in plantarflexion observed preswing since there was no significant differences in knee angle in sagittal plane. Sex differences were also found in the pelvic angular motion in the sagittal plane. The women walked with more anteriorly pelvis tilt, because there was associated between abdominal muscle performance and the angle of pelvic inclination for women but not for men [23], according to that, women seem to have imbalance of the muscles that stabilize the pelvic (the abdominal and the lumbar erector spinae muscles) because of many factors such as pregnancy and unfitness, this imbalance explains the increased females anterior pelvic tilt shown in this study, this requires an electromyogram to confirm this result.

Ankle kinematic and kinetic in sagittal plane showed that the females had greater plantarflexion pre swing ($P = 0.041$) and smaller dorsiflexion moment in the same period ($p = 0.010$). The women participated in this study used to wear high heel as they told. Reportedly, Frequent use of high heels affects the length of the Achilles tendon which becomes shorter, and there was a linear relationship between the length of the Achilles tendon and the ankle dorsiflexion as reported by Costa M.L et al [6]. As shown in figure (4), the second peak of vertical ground reaction force pre swing was smaller for women compared to men due to the acceleration of the body downward by increasing the trunk flexion, this affected the dorsiflexion moment pre swing which was smaller for women. This result has been supported by Toda et al who revealed that the ankle dorsiflexion moment was related to second peak of vertical ground reaction force in the push-off period which is greater for males [19]. Sex differences in ROM_S of the hip and ankle as observed in this study indicate that when walking, women rely more on ankle angular motion, while men rely more on hip angular motion.

There are several limitations in this study, some of the results obtained in this study need to be confirmed by studying the kinematics and kinetics in other planes (coronal plane and transverse plane), and the electromyography for lower limb. Moreover, It is better to have a larger study sample so that the results can be generalized.

6. Conclusion:

Gender differences in walking are of interest in a variety of clinical applications. In most gait studies, males and females are often grouped for analysis or comparsion, however there may be specific cases that require separation. Some gender differences may be manifest in gait and thus affect treatment and rehabilitation strategies. Likewise, the design of gender-specific joint replacements, prosthetics, can also be guided by differences in movement. In order for gender differences to be used effectively in these applications, they must be constantly identified and understood, so we sought to explore the reasons behind the potential differences between the sexes. In conclusion, the findings of this study support and expand evidence about sex differences in gait patterns in sagittal plane. Walking in females is characterized by slower gait speed, shorter stride length, and narrower step width. Also, they walked with less hip range of motion and greater ankle range of motion. Their pelvis tilt was more anteriorly, and hip joint flexion was greater and ankle dorsiflexion moment was smaller, compared with males'.

We therefore recommend that the difference in sex-specific gait patterns should be taken into account when interpreting and treating pathological gait as well as when developing reference biomechanical databases.

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