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Comparison between overweight due to pregnancy and due to added weight to simulate body mass distribution in pregnancy

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ABSTRACT

The assessment of biomechanical loading in the musculoskeletal system of the pregnant women is particularly interesting since they are subject to morphological, physiological and hormonal changes, which may lead to adaptations in gait. The purpose of this study was to analyze the effect of the increased mass in the trunk associated to pregnancy on the lower limb and pelvis, during walking, on temporal-distance parameters, joint range of motion and moments of force, by comparing a pregnant women group to a non-pregnant group, and to this group while carrying a 5 kg additional load located in the abdomen and breasts during walking, to understand which gait adaptations may be more related with the increased trunk mass, or if may be more associated with other factors such as the girth of the thigh. The subjects performed a previous 12 min training adaption to the added load. To calculate ankle, knee and hip joint angles and moments of force, a three-dimensional biomechanical model was developed. The inverse dynamics method was used to estimate net joint moments of force. The increased mass of the anterior trunk associated with second trimester of pregnancy may influence some gait variables such as the left step time, left and right stance times, double limb support time, maximum hip extension, maximum pelvic right obliquity, pelvic obliquity range of motion, maximum transversal left rotation and peak hip flexion moments of force.

1. Introduction

During pregnancy, women are subject to morphological, physiological and hormonal changes, which can lead to adaptations in gait. These changes include weight gain [1,2], extended lower back [3], increased ligamentous laxity [4], decreased neuromuscular control and coordination [5,6], swelling of the arms and legs [7], altered biomechanical parameters such as changes in mechanical loading and joint kinetics [8–10], decreased of abdominal muscle strength [11] and increased spinal lordosis [2]. Also, more than 50% of the women reported swelling of the foot, ankle, and leg, unsteady gait, increased foot width and hip pain [12].

The recommendations for body mass increase of a woman with a normal pre-pregnancy body mass index (BMI) are, on average, between 11.5 and 16 kg, and its distribution depends on different components as the fetus growth, placenta, amniotic fluid, uterus, mammary gland, blood and adipose tissue [13].

While walking on the treadmill, it was found that in pregnancy self-selected velocity was significantly lower, while pelvis and thorax rotation amplitudes were slightly reduced [6]. Gilleard found that sagittal plane range of motion for thoracic, pelvic and thoracolumbar spine and walking velocity, showed no linear trends with advancing pregnancy. In post-birth, the thoracic segment range of motion increase and pelvic range of motion decrease in comparison to late pregnancy [14].

Foti et al. [8] reported an increase in the following variables: stride width, hip moment of force (Mf), power in the frontal and sagittal planes, maximum ankle plantar flexion Mf, and maximum ankle plantar flexion power absorption, use of the abductor and extensor muscles of the thigh and in the use of the ankle plantar flexor muscles.

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The increased use of hip muscles may contribute to the pain in lower back, pelvic and hip. Stride width increase results in a larger base of support during walking, probably to improve locomotor stability [8,15].

When comparing the effect of externally distributed load carriage with the influence of excessive body mass, a greater hip range of motion (ROM) was found in the former [16].

The purpose of this study was to understand which gait adaptations may be related with an increased trunk mass or more associated with other factors such as the girth of the thigh during pregnancy. We have assessed the temporal-distance parameters, joint ROM and Mf of the lower limb and pelvis during walking and compared three groups: pregnant, non-pregnant and non-pregnant women carrying a 5 kg additional load located in the abdomen and breasts during walking. This study is an alternative to those that use a longitudinal approach to characterize the gait changes along pregnancy [8,17].

2. Methods

The study was approved by the ethics committee of FMH – University of Lisbon. All women gave informed consent to participate voluntarily in the study.

The sample consisted of two groups:

(1) Eighteen pregnant women, twelve primiparas and six multiparas, with 27.3 ± 3 weeks of gestational age (second trimester), mean age of 32.6 ± 2.7 years, body mass of 68.2 ± 7.3 kg, height of 1.60 ± 0.1 m and BMI of 26.3 ± 2.6 kg/m^2 and 98.5 cm of abdominal girth.
(2) Eighteen non-pregnant women with mean age of 20.4 ± 1.5 years, body mass of 58.9 ± 8.4 kg, height 1.60 ± 0.1 m and BMI of 21.9 ± 2.7 kg/m^2.

An extra load was added in the abdomen and breasts of the non-pregnant women, providing a representation of this condition and taking into account only this anthropometric characteristic.

A strong large strap adjustable to the abdominal area was constructed in order to load sandbags with 0.5, 1 and 2 kg of mass. The sand allowed adjusting the volume of the extra load to the morphological characteristics of each subject, being tight at the waist with Velcro®.

The non-pregnant group (NPG) performed unloaded and loaded barefoot walking. The load was calculated based on Institute of Medicine recommendations for mass gain during pregnancy [13], which was 0.42 kg/week; we assumed that the mass distribution was 34.3% located in the lower trunk [18] resulting in 4 kg and 0.5 kg in each breast, which value was based on [19] and in the mass distribution for the upper trunk [18]. In this condition the group was called load carrying (LCG), with average values of 64.5 kg of mass, 24 kg/m^2 of BMI and 92.6 cm of abdominal girth.

Reflective spherical markers were placed on anatomical landmarks according to the defined marker setup protocol suggested by Capozzo et al. [20].

Motion capture was performed with an optoelectronic system of twelve cameras Qualisys (Oqus-300) at a frame rate of 200 Hz, synchronized with two force platforms (Kistler AG, Winterthur, Switzerland) and one AMTI (Advanced Mechanical Technology, Inc., Watertown, MA), to collect ground reaction force data. The participants performed three 1-min trials of barefoot walking at a self-selected velocity, with a break of 30 s between each trial, making a total of approximately 20 cycles and the best 5 were selected for analysis. The subjects were not informed about the platforms location.

For load adaptation, the NPG performed a 12 min predefined route with walking and climbing/descending stairs, before data collection.

To reduce noise, the motion data were filtered, using a low pass Butterworth filter, with a cutoff frequency of 15 Hz [21].

A global optimization on the data processing algorithm was performed [22] to reduce the effect of soft tissue artifact. The model assumed a universal joint to the ankle, a revolute joint to the knee and a spherical joint to the hip.

The inverse dynamics method was used to estimate net joint Mf. To calculate ankle, knee and hip joint angles and Mf, the three-dimensional biomechanical models were developed with the software Visual 3D C-Motion, Inc. The weights and locations of the centers of mass for each body segments of the NPG were calculated using the regression equations of Dempster and inertia moments using inertial properties based on their shape [23]. For LCG we added 4 kg on the pelvis mass. For pregnant group (PG) we used relative masses proposed by Jensen [18]. The foot segment was defined by the first and fifth metatarsals, lateral and medial tibia malleolus. The zero ankle angle (neutral position) is approximately 70°, but not changing the ankle ROM.

The results were based on five representative cycles per subject, selected based on the stability of gait. Both angular displacement and Mf data were normalized to time cycle, and Mf was normalized to body mass.

For descriptive statistics, continuous data are presented as mean and standard deviations. For the variables with normal distribution (Shapiro–Wilk test), the comparison between NPG and PG were performed using the Student *t*-test. The Mann–Whitney *U*-test was used when normal distribution was not verified. The comparisons between the NPG and LCG, were carried out by paired-samples *t*-test and the Wilcoxon non-parametric test. Statistical tests were performed using PAWS-19. A $p < 0.05$ was used to denote statistical significance.

3. Results

Concerning the temporal distance parameters (Table 1), right and left stance phase (SP) time, and double limb support time (DLST), PG had higher values when compared to NPG. The right SP represented 60.2% and 59.6% of the gait cycle on PG and NPG, respectively. The left step time increased in PG. Stride width was wider in PG.

Table 1
Comparison of temporal distance parameters mean and standard deviation between groups (1) non-pregnant group (NPG) and pregnant group (PG), (2) NPG and load carrying group (LCG) and (1, 2) PG and LCG.

Variable	NPG	PG	LCG	*p* value
Velocity (m/s)	1.24 ± 0.13	1.16 ± 0.12	1.19 ± 0.16	NPG_LCG) <0.001[b]
Stride width (m)	0.08 ± 0.02	0.10 ± 0.02	0.08 ± 0.02	NPG_PG) 0.025[a] PG_LCG) 0.040[a]
Left step length (m)	0.64 ± 0.06	0.62 ± 0.05	0.63 ± 0.06	NPG_LCG) 0.001[a]
Right step length (m)	0.65 ± 0.06	0.62 ± 0.05	0.63 ± 0.07	NPG_LCG) <0.001[b]
Left step time (s)	0.52 ± 0.02	0.54 ± 0.03	0.53 ± 0.03	NPG_PG) 0.036[a] NPG_LCG) 0.023[a]
Left stance time (s)	0.62 ± 0.04	0.65 ± 0.04	0.64 ± 0.05	NPG_PG) 0.030[a] NPG_LCG) 0.006[a]
Right stance time (s)	0.62 ± 0.03	0.65 ± 0.04	0.63 ± 0.05	NPG_PG) 0.005[a] NPG_LCG) 0.006[a]
Double limb support time (s)	0.19 ± 0.03	0.22 ± 0.03	0.21 ± 0.03	NPG_PG) 0.002[a] NPG_LCG) <0.001[b]

[a] A significant difference (level of significance $p < 0.05$).
[b] A significant difference (level of significance $p < 0.001$).

Compared with NPG, peak eversion angle was 2° higher in PG as the maximum inversion, which also increased in almost 4°. Consequently, the longitudinal foot rotation ROM increased 6° in PG (Table 2). The maximum knee extension angle, occurred at the end of the gait cycle, was lower in PG when compared with NPG and the respective ROM was significantly higher (Table 2). During SP, around 38% of gait cycle, the knee extended more in PG. At the hip, the maximum flexion angle occurred in different phases among the subjects. Thus, at the beginning of the gait cycle, the maximum hip flexion angle was higher in pregnant women, as well as at in the end of the cycle. In the PG, the extension peak value was lower in the pre-swing (Fig. 1). In Fig. 2, we observe that, although the pelvis is more anterior tilted in PG over the 100% of gait cycle, at the end of the SP the maximum anterior pelvic tilt was 6.38° higher in PG compared with NPG. In the end of the gait cycle, maximum posterior pelvic tilt was also higher in PG.

In the coronal plane, maximum pelvic right obliquity angle was lower for PG as well as pelvic obliquity ROM (Table 2).

In the ankle joint PG showed higher peak dorsiflexion moment at the end of the SP. Also inversion peak moment was 0.06 N m/kg higher in PG. In the hip joint, PG had higher hip peak flexion moment. Regarding the adduction moment, it was also higher in PG as the abduction peak moment which had a significant higher value mid stance (33%) of the gait cycle (Fig. 2). Also the internal peak moment was significantly higher in PG.

Significant differences were also found between LCG and NPG. In LCG, double limb support time, right and left stance times, were significantly higher and it was observed slower walking velocity. While carrying the extra load right and left step lengths were shorter. Left step time was higher in LCG; SP was 59.4% of total gait cycle time (Table 1).

At the end of the SP, LCG increased the maximum plantarflexion ankle angle in 6°, when compared with NPG. The maximum knee extension was higher in LCG condition. At the hip, the maximum flexion angle was higher in PG and the extension peak value was lower. During the SP, the maximum knee flexion and extension angles were 3° and 2° higher, respectively, in LCG. The hip maximum flexion angle, increased in LCG, in both instances, after initial contact and in the end of the swing phase (SW). In what concerns the maximum adduction angle, the value in LCG was lower than in NPG, which reduces adduction/abduction ROM. The hip maximum external rotation was significantly lower in LCG as the internal/external rotation ROM. Maximum pelvic right and left obliquity angles were lower for LCG reducing pelvic obliquity ROM. Right and left transverse pelvic rotations and ROM were also lower in LCG (Table 2).

Flexion and adduction hip maximum Mf were higher for LCG at the same point of the SP. The external rotation peak moment was

Table 2
Comparison of ankle, knee and hip ROM mean and standard deviation between groups during stance (SP) and swing phases (SW) (1) non-pregnant group (NPG) and pregnant group (PG), (2) NPG and load carrying group (LCG) and (1, 2) PG and LCG.

Maximum angle and ROM (°)	NPG	PG	LCG	p value
Ankle plantarflexion SP	58.92 ± 12.70	63.53 ± 4.67	64.82 ± 3.83	NPG_LCG) 0.005[a]
Ankle eversion	6.54 ± 10.69	4.41 ± 4.50	7.93 ± 3.78	NPG_PG)0.011[a]
Ankle eversion/inversion ROM	13.30 ± 4.19	19.07 ± 5.11	13.64 ± 3.83	NPG_PG) 0.001[a] PG_LCG) 0.001[a]
Knee flexion SP	23.92 ± 4.61	20.37 ± 6.09	26.83 ± 6.87	NPG_PG) 0.008[a]
Knee extension SP	11.2 ± 4.23	6.18 ± 4.21	13.06 ± 4.86	NPG_PG) 0.002[a]
Knee extension SW*	9.04 ± 4.72	3.37 ± 5.32	11.19 ± 4.76	NPG_LCG) 0.003[a] PG_LCG) <0.001[b] NPG_PG*) 0.001[a] NP_LCG*) 0.010[a] PG_LCG*) <0.001[b]
Knee flexion/extension ROM	54.94 ± 5.11	60.11 ± 5.22	55.45 ± 5.41	NPG_PG) 0.006[a] PG_LCG) 0.004[a]
Hip flexion SP	34.07 ± 3.94	39.91 ± 5.22	37.93 ± 5.82	NPG_PG) 0.001[a]
Hip flexion SW*	34.16 ± 3.89	40.07 ± 5.26	37.58 ± 5.79	NPG_LCG) <0.001[b] NPG_PG*) 0.001[a] NPG_LCG*) <0.001[b]
Hip extension	−8.28 ± 4.25	−3.35 ± 5.27	−5.67 ± 5.54	NPG_PG) 0.004[a] NPG_LCG) 0.001[a]
Flexion/extension hip ROM	42.81 ± 3.79	43.77 ± 3.17	43.97 ± 4.22	NPG_LCG) 0.031[a]
Hip adduction	10.61 ± 3.88	9.18 ± 2.53	8.71 ± 3.47	NPG_LCG) 0.009[a]
Hip adduction/abduction ROM	20.72 ± 5.55	18.58 ± 4.31	17.52 ± 4.62	NPG_LCG) 0.003[a]
Hip external rotation	−17.79 ± 6.51	−20.58 ± 4.72	−14.54 ± 7.78	NPG_LCG) 0.003[a] PG_LCG) 0.008[a]
Hip internal/external rotation ROM	20.49 ± 5.33	20.34 ± 5.02	15.98 ± 5.12	NPG_LCG) <0.001[b] PG_LCG) 0.014[a]
Anterior pelvic tilt	10.23 ± 2.73	16.61 ± 4.49	11.32 ± 4.07	NPG_PG) <0.001[b] PG_LCG) 0.001[a]
Posterior pelvic tilt	6.67 ± 2.56	13.01 ± 4.47	7.46 ± 3.88	NPG_PG) <0.001[b] PG_LCG) <0.001[b]
Pelvic left obliquity	8.25 ± 4.01	6.83 ± 2.51	5.16 ± 3.43	NPG_LCG) <0.001[b]
Pelvic right obliquity	−8.64 ± 2.45	−5.78 ± 3.48	−7.63 ± 2.61	NPG_PG) 0.007[a] NPG_LCG) 0.018[a]
Pelvic obliquity ROM	16.89 ± 5.20	12.61 ± 3.62	12.79 ± 3.97	NPG_PG) 0.007[b] NPG_LCG) 0.003[a]
Pelvic transversal left rotation	8.44 ± 2.72	6.07 ± 3.05	6.20 ± 2.65	NPG_PG) 0.019[a] NPG_LCG) 0.001[a]
Pelvic transversal right rotation	−7.25 ± 3.06	−7.63 ± 3.43	−5.11 ± 3.23	NPG_LCG) 0.005[a] PG_LCG) 0.030[a]
Pelvic rotation ROM	15.69 ± 4.01	13.70 ± 4.95	11.31 ± 3.07	NPG_LCG) <0.001[b]

[a] A significant difference (level of significance $p < 0.05$).
[b] A significant difference (level of significance $p < 0.001$).

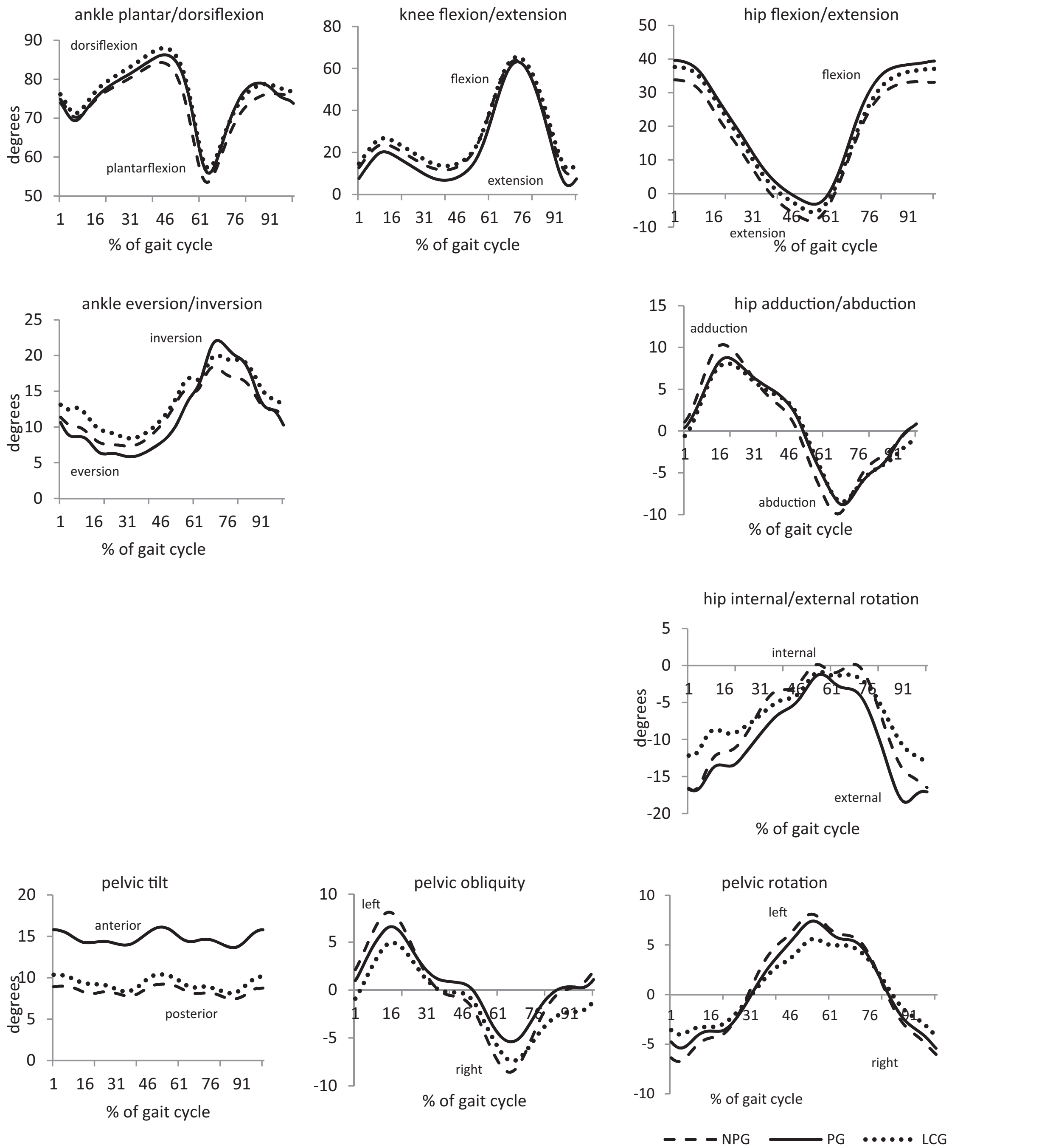

Fig. 1. Ankle, knee, hip and pelvis ROM and pelvis ROM in sagittal (first row), frontal (second row) and transversal planes (third row) for the non-pregnancy (NPG), pregnancy (PG) and load carrying (LCG) groups.

higher in the earlier SP (16% of gait cycle) as well as the abduction peak moment that had significant higher values around 33% of gait cycle (Fig. 2).

Stride was wider in the PG in comparison to LCG. Some kinematic differences were observed: in the frontal plane, the ankle eversion/inversion ROM increased 5° in PG. During SP the knee extension in PG reached values close to 6°, while higher values were observed in LCG (Table 2). The maximum knee extension angle occurred during the terminal swing, where PG presented a more extended knee. Thus, knee ROM remained higher for PG. Maximum hip external rotation was 6° higher in PG, also increasing the ROM. Maximum anterior and posterior pelvic tilt values in PG changed for higher values, not affecting the ROM. On transversal plane, the maximum right rotation angle was also higher in PG.

Regarding Mf, dorsiflexion and inversion peak moments remained the highest in PG. In the loading response, hip adduction and internal rotation peak Mf were also higher in P, as the external peak moment that occurred in the end of the SP (Table 3).

Regarding the trunk ROM, no significant differences were between groups (data not shown).

4. Discussion

To understand the isolated effect of the added trunk mass, comparisons between NPG and load carrying LCG were performed.

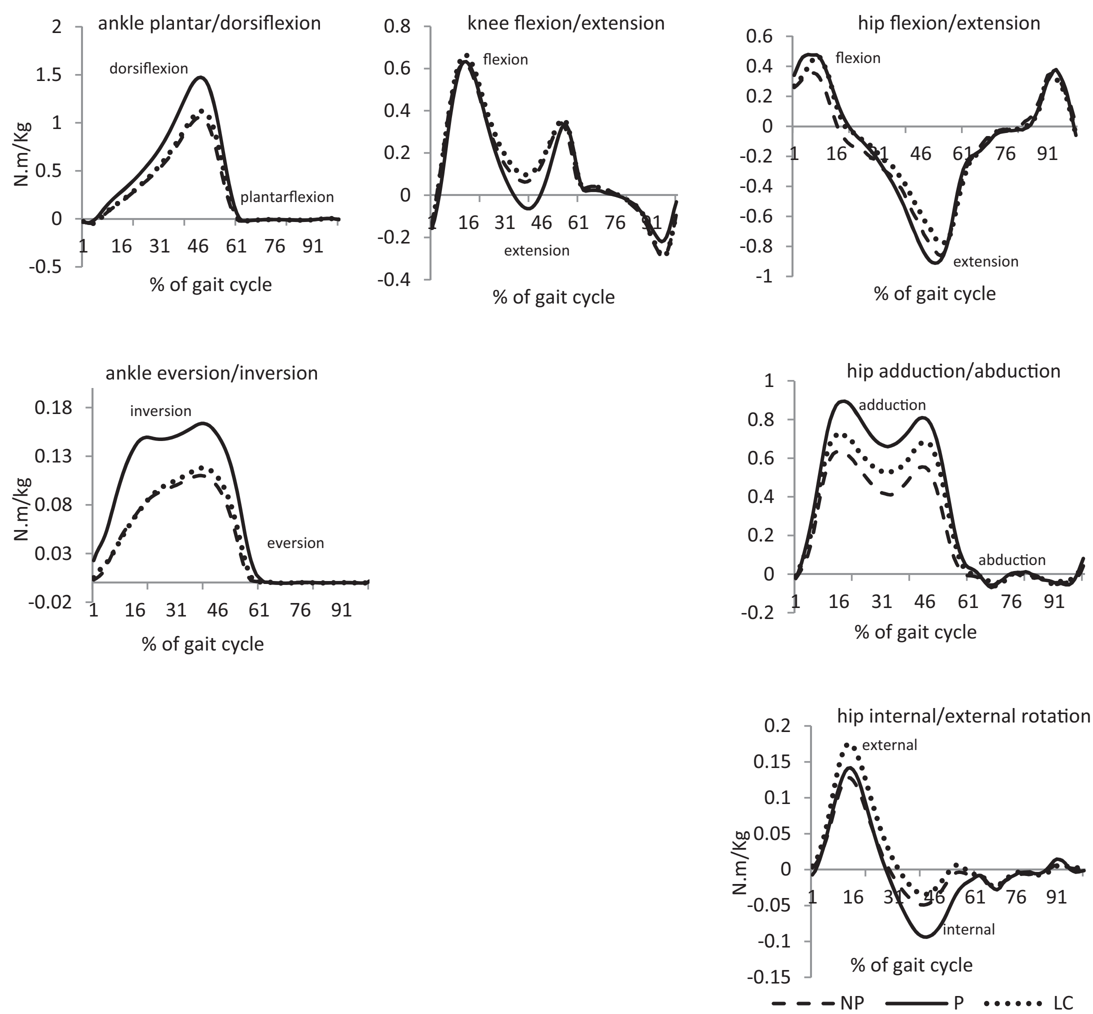

Fig. 2. Ankle, knee and hip joints Mf in sagittal (first row), frontal (second row) and transversal planes (third row) for the non-pregnancy (NPG), pregnancy (PG) and load carrying (LCG) groups.

Table 3
Comparison of ankle, knee and hip peaks Mf mean and standard deviation between groups (1) non-pregnant group (NPG) and pregnant group (PG), (2) NPG and load carrying group (LCG) and (1, 2) PG and LCG.

Normalized peak Mf (N m/kg)	NPG	PG	LCG	*p* value
Ankle dorsiflexion	1.07 ± 0.21	1.50 ± 0.26	1.14 ± 0.22	NPG_PG) <0.001[b] PG_LCG) 0.001
Ankle inversion	0.13 ± 0.05	0.19 ± 0.07	0.13 ± 0.08	NPG_PG) 0.002[a] PG_LCG) 0.018[a]
Hip flexion	0.41 ± 0.13	0.53 ± 0.11	0.49 ± 0.16	NPG_PG) 0.008[a] NPG_LCG) <0.001[b]
Hip extension	−0.89 ± 0.14	−0.93 ± 0.24	−0.81 ± 0.14	NPG_LCG) 0.004[a]
Hip adduction	0.67 ± 0.19	0.92 ± 0.16	0.77 ± 0.21	NPG_PG) <0.001[b] NPG_LCG) 0.006[a] PG_LCG) 0.014[a]
Hip abduction	0.02 ± 0.56	0.05 ± 0.04	0.01 ± 0.07	NPG_PG) <0.001[b] NPG_LCG) 0.023[a]
Hip external rotation	0.13 ± 0.05	0.15 ± 0.03	0.18 ± 0.08	NPG_LCG) <0.001[b]
Hip internal rotation	−0.06 ± 0.02	−0.10 ± 0.05	−0.05 ± 0.02	NPG_PG) 0.023[a] PG_LCG) 0.002[a]

[a] A significant difference (level of significance $p < 0.05$).
[b] A significant difference (level of significance $p < 0.001$).

In these groups the subjects are the same, thus, significant differences in a variable between them are relevant. If there is a significant change in a variable value when the same subject has a weight applied to her we could confirm that increased weight will be relevant for the change in this variable. In the comparisons between NPG and PG, we use this fact to give strength to the changes related to the real increased trunk mass associated to pregnancy. Three conditions were defined, and from here on, comparisons between NPG and PG are designated by (NPG vs. PG), NPG and LCG by (NPG vs. LCG) and PG and LCG by (PG vs. LCG). From these comparisons, three sets of particular variables were found.

In set I, there are significant differences in a variable in (NPG vs. PG) and (NPG vs. LCG), and no difference in (PG vs. LCG). From the difference in (NPG vs. LCG), as mentioned above, we have clear relation between the extra weight and changes on the variable. Differences in (NPG vs. LCG) would make us expect differences in (NPG vs. PG), which is the case. No changes in (PG vs. LCG) reinforce the fact that weight is influent on the change in the variable.

In the set I we find the variables: left step time, left stance time, right stance time, double limb support time, maximum hip extension, maximum pelvic right obliquity, pelvic obliquity ROM, maximum transversal left rotation and peak hip flexion Mf. The trunk weight gain increases both SP duration and DLST in both LCG and PG [24]. The body's response of PG and LCG to the increased external hip flexor moment is related to an increased work of the hip flexors to support the anterior additional mass of the trunk.

Mechanical constraints of controlling the increased inertial load lead to a decrease in the pelvis amplitude in the frontal and transversal planes. The hip joint is adjacent to the pelvis and can be more affected by the lower trunk weight gain.

In set II, we have differences in (NPG vs. PG), (NPG vs. LCG) and (PG vs. LCG). This is similar to set I, but the fact that the variable is significantly different in (PG vs. LCG) weakens the connection between the extra load and the change in the variable. This difference could be explained by the fact that weight is distributed differently in LCG and PG, and in PG the subject had several months of adaptation to a gradual weight increase, and hormonal and physiological changes that adapt the body to extra load, whereas in LCG the subject is not changed apart from the extra weight, adaptation to it consisting of no more than 12 min of physical activity.

In relation to this set, three variables were found: maximum knee extension during the SP, maximum knee extension during the swing phase and peak hip adduction Mf. Women in PG extend more the knee, during stance and swing phases. Furthermore, hip peak adduction Mf increases, which may be a consequence of a wider stride for PG.

In set III, there are differences in (NPG vs. PG) and (PG vs. LCG), and no differences in (NPG vs. LCG). The fact that a variable is not different in (NPG vs. LCG) shows some independence of it to weight. Therefore, the differences in (NPG vs. PG) could be attributable to other mechanical factors such as the girth of the thigh during pregnancy or the fact that the subjects are different. The difference in (PG vs. LCG) is consistent with this observation. In conclusion, the variables in set I show a statistically significant dependence on weight, those in III on other factors, those in set II being in between.

Set III includes the following variables: stride width, maximum ankle eversion, eversion/inversion ankle ROM, flexion/extension knee ROM, maximum anterior pelvic tilt, maximum posterior pelvic tilt, peak ankle dorsiflexion Mf, peak ankle inversion Mf and peak hip external rotation Mf. Stride width is higher in PG, thus creating a larger base of support and thereby providing more stability [8,15]. Ankle maximum dorsiflexion and inversion angles decrease during the second trimester of pregnancy [13]. Pregnant women do more eversion and increase eversion/inversion ankle ROM [25], which might be related to joint laxity associated to pregnancy or related to a wider step width. During the loading response, in the sagittal plane, maximum plantarflexion Mf reduces to zero during the earlier SP. From this instant on, dorsiflexion moment increases, reaching higher peak values in P, and the effect of body weight is shown in the acceleration of the downward fall [26]. The decrease in the maximum dorsiflexion ankle angle and increase in peak ankle dorsiflexion Mf on PG, suggests that dorsiflexor muscles are more active during the second trimester of pregnancy. Also the peak inversion Mf increases at the subtalar joint, could be a response to controlling the body motion, consequential to an increased step width or an increased passive ROM at the subtalar joint during pregnancy [25], which means that the inverter muscles of this joint (tibialis posterior and anterior, the flexor digitorum longus, the flexor hallucis longus, and soleus) are more active in order to control the ankle [26]. Immediately before heel strike, pregnant women extend more the knee and the respective ROM, while hip flexion increases [18,19], which in turn may be a consequence of an increased anterior pelvic tilt [9,19]. Other studies indicate that increased pelvic tilt is typically related with increased lumbar lordosis [27]. The same happens in the terminal swing where the knee is again more extended and the hip more flexed in PG.

The anterior increased mass of the trunk associated with second trimester of pregnancy may influence some gait variables such as the left step time, left and right stance times, double limb support time, maximum hip extension, maximum pelvic right obliquity, pelvic obliquity ROM, maximum transversal left rotation and peak hip flexion Mf.

Concerning trunk movements, the results were not conclusive possibly due to the small number of studied subjects.

The use of extra load in the trunk is not a simulation of pregnancy condition, and this issue needs more attention, particularly concerning the distribution and the adaptation to it. The thigh segment should also be included in the mass distribution. The relation between anterior trunk extra weight and gait modifications needs further research since pregnancy weight gain provides higher biomechanical joint loads during walking causing injuries, pain or discomfort.

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References

[1] Chesley LC. Weight changes and water balance in normal and toxic pregnancy. Am J Obstet Gynecol 1944;48:565–93.
[2] Dumas G, Reid J, Wolfe L, Griffin M, McGrath M. Exercise, posture, and back pain during pregnancy. Clin Biomech 1995;10:98–103.
[3] Whitecome K, Shapiro L, Lieberman D. Fetal load and the evolution of lumbar lordosis in bipedal hominis. Nature 2007;450:1075–80.
[4] Calguneri M, Bird HA, Wright V. Changes in joint laxity occurring during pregnancy. Ann Rheum Dis 1982;41:126–8.
[5] Wu W, Meijer OG, Jutte PC, Uegaki K, Lamoth CJ, Sander de Wolf G, et al. Gait in patients with pregnancy-related pain in the pelvis: an emphasis on the coordination of transverse pelvic and thoracic rotations. Clin Biomech (Bristol Avon) 2002;17:678–86.
[6] Wu W, Meijer OG, Lamoth CJ, Uegaki K, van Dieen JH, Wuisman PI, et al. Gait coordination in pregnancy: transverse pelvic and thoracic rotations and their relative phase. Clin Biomech (Bristol Avon) 2004;19:480–8.
[7] Kent T, Gregor J, Deardorff L, Katz V. Edema of pregnancy: a comparison of water aerobics and static immersion. Obstet Gynecol 1999;94:726–9.
[8] Foti T, Davids JR, Bagley A. A biomechanical analysis of gait during pregnancy. J Bone Joint Surg Am 2000;82-A:625–32.
[9] Gilleard W, Crosbie J, Smith R. Effect of pregnancy on trunk range of motion when sitting and standing. Acta Obstet Gynecol Scand 2002;81:1011–20.
[10] Lymbery JK, Gilleard W. The stance phase of walking during late pregnancy: temporospatial and ground reaction force variables. J Am Podiatr Med Assoc 2005;95:247–53.
[11] Gilleard W, Brown J. Structure and function of the abdominal muscles in primigravid subjects during pregnancy and the immediate postbirth period. Phys Ther 1996;76:750–62.
[12] Ponnapula P, Boberg J. Lower extremity changes experienced during pregnancy. J Foot Ankle Surg 2010;49:452–8.
[13] IOM, NRC. Weight gain during pregnancy. Reexamining the guidelines. Washington, DC: The National Academies Press; 2009.
[14] Gilleard W. Trunk motion and gait characteristics of pregnant women when walking: report of a longitudinal study with a control group. BMC Pregnancy Childbirth 2013;13(71).
[15] Bird A, Menz H, Hyde C. The effect of pregnancy on footprint parameters. A prospective investigation. J Am Podiatr Med Assoc 1999;89(8):405–9.
[16] Smith B, Roan M, Lee M. The effect of evenly distributed load carrying on lower gait dynamics for normal weight and overweight subjects. Gait Posture 2010;32:176–80.
[17] Hagan L, Wong C. Gait in pregnant women: spinal and lower extremity changes from pre- to postpartum. J Womens Health Phys Therap 2010;34(2):46–56.
[18] Jensen RK, Doucet S, Treitz T. Changes in segment mass and mass distribution during pregnancy. J Biomech 1996;29:251–6.

[19] Hytten F, Chamberlain G. Clinical physiology in obstetrics. Oxford: Blackwell Scientific Publications; 1991.
[20] Capozzo A, Cappello A, Della Croce U, Pensalfini F. Surface-marker cluster design for 3-D bone movement reconstruction. IEEE Trans Biomed Eng 1997;44(12):1165–74.
[21] Winter DA. The biomechanics and motor control of human gait: normal, elderly and pathological. Ontario: University of Waterloo Press; 1991.
[22] Lu TW, O'Connor JJ. Bone position estimation from skin marker coordinates using global optimization with joint constraints. J Biomech 1999;32:129–34.
[23] Dempster WT. Space requirements of the seated operator: geometrical, kinematic, and mechanical aspects of the body with special reference to the limbs. WADC Technical Report 55-149. OH: Wright-Patterson Air Force Base; 1955.
[24] Lai P, Leung A, Li A, Zhang M. Three-dimensional gait analysis of obese adults. Clin Biomech 2009;23:S2–6.
[25] Block RA, Hess LA, Timpano EV, Serlo C. Physiological changes in the foot in pregnancy. J Am Podiatr Med Assoc 1985;75:297–9.
[26] Perry J. Gait analysis. Normal and pathological function. New Jersey: SLACK Inc.; 1992.
[27] Franklin M, Conner-Kerr T. An analysis of posture and back pain in the first and third trimesters of pregnancy. J Orthop Sports Phys Ther 1998;28(3):133–8.