COMPARATIVE ANALYSIS OF THE GROUND REACTION FORCES, DURING THE SUPPORT PHASE, IN A GROUP OF PREGNANT WOMEN ON THEIR 3RD TRIMESTER OF PREGNANCY AND IN A GROUP OF NOT PREGNANT WOMEN

Análise comparativa de forças de reação do solo durante a fase de apoio em um grupo de mulheres grávidas no 3º trimestre de gestação e em um grupo de mulheres não-grávidas

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Abstract

PURPOSE: To analyze and compare the Ground Reaction Forces (GRF), during the stance phase of walking in pregnant women in the 3rd trimester of pregnancy, and non pregnant women. **METHODS**: 20 women, 10 pregnant and 10 non pregnant, voluntarily took part in this study. GRF were measured (1000 Hz) using a force platform (BERTEC 4060-15), an amplifier (BERTEC AM 6300) and an analogical-digital converter of 16 Bits (Biopac). **RESULTS**: The study showed that there were significant differences among the two groups concerning absolute values of time of the stance phase. In what concerns to the normalized values the most significant differences were verified in the maximums values of vertical force (Fz3, Fz1) and in the impulse of the antero-posterior force (Fy2), taxes of growth of the vertical force, and in the period of time for the antero-posterior force (Fy) be null.

CONCLUSIONS: It is easier for the pregnant to continue forward movement (push-off phase). O smaller growth rates in what concerns to the maximum of the vertical force (Fz1) for the pregnant, can be associated with a slower speed of gait, as an adaptation strategy to maintain the balance, to compensate the alterations in the position of her center of gravity due to the load increase. The data related to the antero-posterior component of the force (Fy), shows that there is a significant difference between the pregnant woman's left foot and right foot, which accuses a different functional behavior in each one of the feet, during the propulsion phase (TS).

Keywords: Gait; Stance phase; Lower extremities; Gait asymmetry.

Resumo

***OBJETIVO**: caracterizar e comparar as forças de reação do solo (FRS), durante a fase de apoio num ciclo de marcha da mulher grávida do 3º trimestre e na não grávida. **MATERIAL E MÉTODOS**: 20 mulheres, 10 grávidas e dez não grávidas, participaram voluntariamente neste estudo. Os valores relativos às forças de reação do solo (FRS) foram medidos (1000 Hz) usando uma plataforma de força (BERTEC 4060-15), ligada a um amplificador (BERTEC AM 6300) e a um conversor analógico-digital de 16 Bits (Biopac). **RESULTADOS**: O estudo demonstrou que existem diferenças significativas entre os dois grupos no que diz respeito aos valores absolutos do tempo de apoio. No que diz respeito aos valores normalizados, as diferenças significativas verificaram-se nos valores máximos da componente vertical da FRS (Fz3), nos impulsos das componentes antero-posterior e vertical (Fy2 e Fz1), nas taxas de crescimento da componente vertical (Fz1 e Fz3), e no tempo para a componente antero-posterior (Fy) se anular. **CONCLUSÕES**: A grávida tem maior facilidade no movimento para a frente (fase de push-off). As menores taxas de crescimento no que diz respeito ao 1º máximo da componente vertical da FRS na grávida, podem estar associadas a uma menor velocidade da marcha como uma estratégia de adaptação para manter o equilíbrio, para compensar as alterações na posição do centro de gravidade devido ao aumento da carga. Os dados relativos ao valor máximo da componente antero-posterior (Fy2) mostram diferenças significativas entre os dois pés da grávida, o que denota um comportamento funcional diferente para cada um dos pés durante a fase de propulsão.*

***Palavras-chave**: Marcha; Fase de apoio; Membros inferiores; Assimetria da marcha.*

INTRODUCTION

Physical exercise associated to the changes due to pregnancy in neuromusculoskeletal, cardiovascular and lung systems, as well as the endocrine and thermoregulatory behaviour, have been and continue to be object of systematic and exhausting studies concerning their repercussions in mother and fetus (1, 2).

There are few studies about human gait and its characterization (3-11), however, in what concerns to the pregnant women's gait, the number of studies founded were scarce and sometimes presented paradoxical results. The literature reviewed about walking and pregnancy, points out an increase in the total time of support phase (12), with a consequent decrease of speed; modifications in the pressure peaks values regarding the hindfoot and metatarsal's head, with contradictory results, and an increase in the movement base (13, 14).

The purpose of this study is to analyze and compare the Ground Reaction Forces (GRF), during the stance phase of walking in pregnant women in the 3rd trimester of pregnancy, and non pregnant women, as well as detecting any eventual functional asymmetries among de lower limbs, within and between groups.

MATERIAL AND METHODS

Sample and experimental conditions

Data were obtained from 20 volunteer women, without history of lesions of the neuromusculoskeletal system, 10 pregnant in their last trimester of pregnancy (mean of 32,8 ± 4,2 weeks) and 10 non pregnant women. They were aged between 23 and 37 years old (mean 30,0 ± 4,0 years old) and a mean height of 1,62 ±0,07m. The mean weight in the pregnant was of 70,3 ± 8,7 kg and in the non pregnant of 58,6±10,8 kg. All women were right handed.

After explaining the study and clearing up any doubts, the women were helped to choose of among the shoes "pattern" available, the ones that better adapted to their feet.

After a brief adaptation, each subject, that was advised to use a gait as normal as possible, walked at a freely chosen speed, on a flat and leveled corridor (500 cm x 92 cm x15 cm), in which a force's platform was engraved.

Data was collected regarding three valid rehearsals of each passage on the platform (right foot, left foot). The acquired data was made during the afternoon, along three months.

This investigation was approved by the Faculty of Sciences of the Sport and Physical Education of the University of O'Porto, Portugal and before starting, each subject gave her informed consent.

Instruments

To collect the GRF data it was used a force platform (Bertec 4060 - 15), a signs amplifier (BERTEC AM 6300) and a 16 Bites analogical-digital conversion unit (BIOPAC). All of the data associated to the electrical sign sent by the platform were amplified 10 times, except the sign regarding Fz (5 times). The sampling rate was of 1000 Hz and a PC with Acqknowledge 3.7.1 (Biopac, Inc.) software processed the electrical signal.

Analyzed parameters

The ground reaction forces on the reference foot, during the stance phase of the gait cycle (GC), are biomechanical variables that have already showed to have a standard behavior (5, 15), specifically in what concerns to its vertical and horizontal (antero-posterior) components, that present a characteristic form.

The force platforms are the most used trustworthy devices known for the determination of this force. These devices allow us to obtain the components of this force in three different directions: Fz - in the vertical direction, Fy - in the antero-posterior direction and Fx - in the medium-lateral direction. The medium-lateral component was not analyzed in this study due to large range of possible values.

The components of the ground reaction forces, maximum and minimum, that act in specific instants of the phase of support of the GC, were the studied.

The GC phases where the maximum value of the vertical component of GRF, F1 and F3 occur are the weight acceptance (WA) and the terminal support phase (TS) correspondingly. The minimum force, F2, located in the valley, happens during the mid stance phase (MS).

The GRF parameters analyzed are shown in Table1.

TABLE 1 - Definition of the dynamic variables and kinematics selected for the study

Symbol	Description
t	Total time of support
Fz1	Maximum vertical force (1st peak).
t_{Fz1}	Period of time for the occurrence of the maximum vertical force F1.
Fz2	Minimum vertical force (valley).
t_{Fz2}	Period of time for the occurrence of the minimum vertical force F2.
Fz3	Maximum vertical force (2nd peak).
t_{Fz3}	Period of time for the occurrence of the maximum vertical force F3.
Rg_{Fz1}	Growth rate of the force F1. (Defined as the reason among F1, normalized to the weight, and the time, normalized at the total time of support, to reach this peak).
Rg_{Fz3}	Growth rate of the force F3. (Defined as the reason among F3, normalized to the weight, and the time, normalized at the total time of support, to reach this peak).
I_{Fz1}	Impulse of the force FZ in the interval [0, t Fz1].
I_{Fz3}	Impulse of the force FZ in the interval [t Fz2, t Fz3].
Fy1	Forces antero-posterior maximum, in the posterior sense.
t_{Fy1}	Period of time for the occurrence of the maximum antero-posterior force, in the posterior sense.
Fy2	Forces antero- posterior maximum, in the anterior sense.
t_{Fy2}	Period of time for the occurrence of the maximum antero- posterior force, in the anterior sense.
I_{Fy1}	Braking impulse (integral of Fy in order t, from t=0 to the instant in that Fy achieves null value).
I_{Fy2}	Acceleration pulse (integral of Fy in order t, from the instant in that Fy reaches null to detach of the foot).
$t_{Fy=0}$	Period time for the horizontal force (Fy) achieve null value.
(W)	Normalized to the weight
(%)	Normalized at the total time of support
(W%)	Normalized to the weight and to the total time of support

The whole statistical treatment was made with SPSSWin11.5.

The same procedure was applied to the statistical analysis of all the studied variables.

The test of Kolmogorov-Smirnov was applied to verify which variables presented normal distribution. The test of Levene was used to verify the homogeneity of the population variances.

The cases in which the distribution was normal, the t-test was applied for independent samples, for a level of significance of $p < 0.05$.

In the remaining cases, the statistical no parametric Mann-Whitney test was applied, for the same significance level.

RESULTS AND DISCUSSION

The study was planned out and executed to detect eventual functional asymmetries among the lower limbs, within each groups and between the groups. In that sense, and as well as it is suggested in some studies (9, 16, 17), the results are presented and analyzed for each one of the subject's feet.

The analysis of the data presented in Table 2, revealed up some significant differences between the two groups. The time of support and the values of Fz1 and Fz2, are significantly higher in the pregnant group. Regarding Fz3 component, the pregnant woman showed significantly higher values only in the left foot. The lack of significance regarding the right foot can be justified by the fact that a pregnant women (larger mass), employs smallest force, for effect of inertia, to continue the movement to the front.

The higher period of time of support phase in the pregnant group, comparatively to the non pregnant group can suggest a lower speed of the gait. This increase in the total time of support, stipulates different periods of time that takes to occur the two peaks Fz1 and Fz3, as well as the minimum (Fz2), as shown in some studies regarding the transport of loads in school backpacks (18), and in the obese children's cinematic analysis (19).

TABLE 2 - Medium values (M) and respective standard deviation (SD), of the support times, the maximum and minimum of the vertical component of ground reaction forces and of the associated impulses Fz1 and Fz3, for the right and left feet. Percentage increase/decrease between the two groups

	Pregnant	Non Pregnant	Pregnant	Non Pregnant	(right)	(left)
	(right foot)	(right foot)	(left foot)	(left foot)		
	M (SD)	M (SD)	M (SD)	M (SD)	%	%
t (s)	1.03 (0.09)*	0.87 (0.07) *	0.97 (0.09) *	0.86 (0.09) *	18,4	12,8
Fz1	706.9 (88.2) *	600.1(102.4) *	725.8 (100.1) *	604.4 (114.1) *	17,8	20,1
Fz2	617.1 (116.0) *	495.0 (68.3) *	639.1 (89.6) *	503.3 (68.0) *	24,7	27,0
Fz3	736.2 (87.6)	651.0 (148.4)	756.1 (96.8) *	640.7 (130.2) *	13,1	18,0
I_{Fz1}	155.05 (54.19) *	88.31 (14.84) *	156.01 (49.21) *	103.17 (53.47) *	75,6	51,2
I_{Fz3}	178.00 (56.23) *	121.90 (24.77) *	148.02 (49.84)	118.44 (17.69)	46,0	

* Significant statistical differences for $p < 0.05$

The absolute impulses of the Fz1 and Fz3 forces, are significantly different ($p<0.001$ - right foot and $p<0.05$ - left foot), presenting a higher value for the pregnant, as it would be expected, since the intensity of the forces Fz1 and Fz3 and the respective times have higher values.

In the case of Fz3 impulse left foot (IFz3_E), a similarity is established between the pregnant and non pregnant gait, this can be associated with possible asymmetries at the level of the lower limbs. To prove it would be necessary a larger study, including pregnant women in the beginning and in the end of pregnancy. The largest value of the impulses corresponds to a larger variation in the amount of movement, which may indicate that the hypothetical decrease of speed isn't enough to compensate the effect of a largest mass, in the support phase, during the sub phases of WA and TS.

Analysis of normalized forces values and respective times

To characterize the eventual differences in the support dynamics during the gait in the two groups, the two components of the Ground Reaction Force were analyzed, vertical (Fz) and antero-posterior (Fy), normalized to the weight. They were also analyzed the periods of time analogous to each one of the forces, normalized to total time of support(t).

From the global analysis of the results presented in Table 3, it's verified that the pregnant women group present lower values for the F3 force normalized to the weight, Fz3(W) (-5,1% in the left foot) and higher values relating to the support's phase normalized time, the fz1 force, t Fz1 (%) (8,2 left foot and 10,8 right foot).

The slightest relative increase Fz3(W), specially as to the left foot, suggests that the pregnant woman use a smaller force in the push-off phase, which can be associated with a higher unbalance, due to the additional load's foremost placement common at the final phase of the pregnancy, in accordance with the studies published by Mota and Link (19).

The fact that the pregnant take longer time in the weight acceptance phase (WA), can be associated to a lower speed, as a strategy to maintain the equilibrium.

The growth rate analysis of Fz1 and Fz3 forces (Figure 2), shows that the pregnant group presented minor values in RgFz1(W%) (-7,4% left foot, -12,9% right foot), which can be explained by the shortest duration of each one of the phases analyzed. This indicates a "superior easiness" in the

attack of the ground and accommodation of the weight, by the non pregnant. These results are similar to some other author, relating the transport of loads in backpacks, which show a decrease of RgFz1 with the load increase (18). On the other hand, some authors (20-22) associate the diminutive values of the growth rate of Fz1 force with a better control of those forces distribution, as a strategy to decrease the impact and to protect the locomotor system's passive structures implicated in the mechanical shock's absorption mechanism.

It's observed, in this study, that there is a decrease in the value of the pregnant's support phase normalized time for the relative maximum Fy, tFy2 (%), mainly for the right foot (-23,2%), confirming the pregnant women's easiness to continue the frontal movement, which is translated in lower periods of time that a pregnant takes to reach Fy2. Significant differences are not observed in the values of Fy normalized to the weight, Fy1(W) and Fy2(W), in spite of the fact that the absolute value average to be inferior in the pregnant, which, associated to the values of p close to 5% (p=0.052), can reveal a tendency, that could be verified in a larger study, specially if the sample includes pregnant observed in different periods of gestation.

The $t_{Fy=0}$(%) higher values regarding the pregnant (7,3% left foot), may indicate a greater difficulty (and more care) in the break off, during the WA phase.

The values obtained for the antero-posterior maximum force, regarding both feet, as shown in the Figure 1, point out an accentuated asymmetry in the two groups. The asymmetry index, regarding the pregnant group, is of 19% and was achieved by applying the formula used by Herzog et al (23).

In this study all women affirmed to be right handed. So the great asymmetry verified in the pregnant, can be associated to the fact that in the pregnant, the increase of the uterine volume becomes to follow a dextrorotation (24), what implies an asymmetric load increase on feet. On the other hand, this fact is also responsible for the greater edema of right foot, consequence of a bigger compression of the right pelvic vases, which cause reduction of the ipsilateral venous return, contributing for a bigger increase of the volume of right foot (24). For all that, it would be the left leg the responsible for conducting the body during walking.

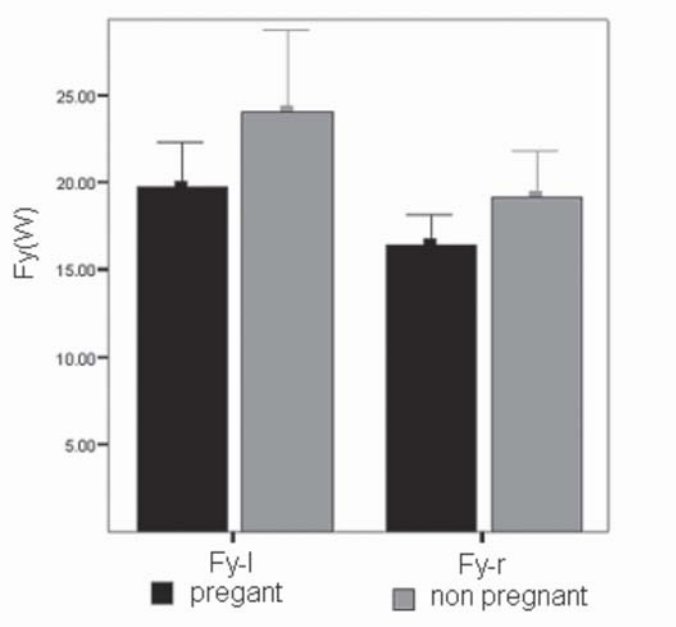

FIGURE 1 - Maximum values of the antero-posterior Force (Fy) normalized to the corporal weight, regarding right and left feet, in the two groups

The symmetry degree between the two feet, during the gait, can be used to detect alterations in its functional behavior (16).

TABLE 3 - Normalized medium values and respective standard deviation, of the GRF vertical component maximum and minimum, of Fz1 and Fz3 growth rates, of the horizontal component (Fy) maximum and minimum and respective periods of time, of the associated impulse Fy2, of the time that takes force Fy to get null, for right and left feet. Percentage increase/decrease between the two groups

	Pregnant (right foot)	Non Pregnant (right foot)	Pregnant (left foot)	Non Pregnant (left foot))	(right)	(left)
	M (SD)	M (SD)	M (SD)	M (SD)	%	%
Fz1 (W)	102.57 (1.41)	104.78 (4.52)	105.23(4.48)	105.22(4.77)		
t_{Fz1}(%)	31.84 (2.37) *	29.43 (2.07) *	30.52 (2.43) *	27.54 (3.36) *	8,2	10,8
Fz2 (W)	90.90 (6.08)	87.68 (6.75)	92.62 (3.64)	88.42 (7.12)		
t_{Fz2}(%)	49.50 (4.58)	50.34 (3.66)	51.38 (6.59)	49.68 (4.48)		
Fz3 (W)	109.72 (3.38)	111.31(5.47)	106.92(2.53) *	112.71(6.49) *		-5,1
t_{Fz3}(%)	74.77 (2.69)	75.39 (5.31)	72.16 (10.00)	70.53 (12.23)		
Rg_{Fz1}(W%)	3.11 (0.29)*	3.36 (0.27) *	3.38 (0.31) *	3.88 (0.58) *	-7,4	-12,9
Rg_{Fz3}(W%)	1.52 (0.32)	1.64 (0.31)	1.46 (0.05)	1.49 (0.08)	-7,3	
Fy1(W)	-9.09 (2.34)	-10.05 (2.91)	-7.99 (2.72)	-8.51 (2.99)		
t_{Fy1}(%)	19.26 (7.34)	22.64 (8.35)	21.54 (8.77)	21.91 (8.26)		
Fy2(W)	16.38 (2.43)	19.17 (3.68)	19.82 (3.53)	24.12 (6.44)		
t_{Fy2}(%)	80.51 (3.13) *	84.03 (1.99) *	57.55 (24.47)*	74.96 (14.04)*	-4,2	-23,2
$t_{Fy=0}$(%)	43.80 (6.36)	46.68 (7.24)	43.54 (6.11) *	40.57 (9.49) *		7,3
I_{Fy2}(W%)	4.61 (1.33)*	3,50 (0.76) *	3.86 (1.74)	4.34 (1.45)		

* Significant statistical differences for $p < 0.05$

In conclusion, the analysis of the data relative to the Ground Reaction Forces (GRF) and respective times of occurrence of notable points, showed a substantial reduction in the second maximum F3 value, which indicates that is easier for the pregnant to continue the movement (push-off phase). This fact is confirmed by the results of the normalized values and the measures, which confirm that the pregnant take less time to reach the acceleration Fy2 phase. The largest mass and its foremost location work as an aid in the forward impulse. The fact that a pregnant takes a longer period of time in the first part of the weight acceptance phase (WA) and to present smaller F1 growth rates, can be associated with slower speed of gait, as an adaptation strategy to maintain the balance, to compensate the alterations in the position of her center of gravity due to the load increase.

The analysis of the data related to the Fy2 force, shows that there is a significant difference between the pregnant woman's left foot and right foot, which accuses a different functional behavior in each one of the feet, during the propulsion phase (TS).

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