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Temporal and spatial parameters of gait during pregnancy

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Purpose: The objective of this study was to describe spatial and temporal parameters during gait in pregnant women, and to compare it with women in post-partum and with a control group. Methods: To investigate alteration in natural locomotion, we used an electronic walkway (GAITRite system). Fifty-eight pregnant women (four last months of pregnancy), nine post-partum women and twenty-three healthy nulligravidae women participated in this study. The women performed the motor task at three different speeds: preferred, fast and slow. Spatial and temporal parameters for pregnant and non-pregnant were compared. Results: In pregnant women, gait speed, step length and cadence were reduced. Consequently, cycle time was longer. The gait cycle was modified by an increase of stance phase and a decrease of swing phase. As a result, an increase of double support and a decrease of single support phases were observed. Step width increased by 15%. Conclusions: The pattern of gait displayed significant modifications during pregnancy as compared to nulliparous women. These changes favour a more stable and safe gait. After childbirth, women kept some characteristics of gait in pregnancy during 8 months.

Key words: *pregnancy, gait analysis, GAITRite*

1. Introduction

There are many anatomical changes during pregnancy: increased body mass, body mass distribution, endocrine system alterations and changes in musculotendinous strength.

For a normal weight, the body mass increases by a mean of 11 to 16 kg during pregnancy [19]. The size of the foetus changes more during the second trimester of pregnancy. This period is associated with significant weight gain in pregnant women (0.56 kg/week vs. 0.52 kg/week for the third trimester) [1]. This change induces a change of body-mass distribution and a modification of the center of inertia of the future mother [13].

During pregnancy, lumbar lordosis increases from a mean angle of 32° ± 12° in early pregnancy to 50° ± 12° at term. Lumbar lordosis adjustment enables women to maintain a stable antero-posterior position of center of mass despite the augmentation of fetal weight [24]. Therefore, the augmentation of lumbar lordosis is correlated with fetal weight.

Nevertheless, for Wang [22], the position of the center of mass displaces superiorly and anteriorly. This movement induces an increased instability and a risk of falls.

According to Kristiansson [15] relaxine increases joint laxity, particularly in the pelvic girdle, causing excessive mobility and instability. However, for Schauberger [20] joint laxity during pregnancy is not the reflection of changes in relaxine levels. The effect of increased ligament laxity is a slightly larger range of movement in the pelvic joints. If this is not compensated by adapted neuro-motor control, pain may result [21].

Consequently, there is a change in the musculoskeletal system and its solicitation that results in neuromuscular adaptations that can modify or alter gait and movements in pregnant women. Increased instability in pregnant women seems to reach unanimity among authors. This instability is related to

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weight increase and the movement of the center of gravity, which causes an increase of postural sway [13], [21].

According to several authors [9], [18], gait remains unchanged in pregnant women with similar speed, cadence and stride length, and stable kinematic parameters [8]. For other authors, the gait of pregnant women is modified. Falola [7], Forczek [8] and Gottschall [10] observed a slower gait, with a decrease in walking frequency and stride length and increased step variability. These parameters are modified in order to promote safety during pregnancy.

There is an increase in double support time and decreased single support as compared to post-partum and nulliparous women. These are fine adjustments that minimize the time on one leg to reduce muscle solicitation [2], [9]. Thus, pregnant women exaggerate transition phases in order to increase the security of gait [10]. This seems related to the fact that, due to increasing abdominal volume, the pregnant woman's field of view changes implying the develoment of strategies to maintain a stable gait. Most studies agree on an increase of step width by 10% [8]–[10], [18].

For kinetic parameters, Foti [9] and Gottschall [10] found overuse of hip abductors, hip extensors and plantar flexors. This excessive muscle use may be a factor in low back pain or pregnancy-related pelvic pain (PRPP) [9]. In contrast, the study of Branco [2] showed a decrease in hip extensor and abductor use. Increased muscle activity seems necessary to compensate the increase in mass, the displacement of the center of pressure and to maintain stable kinetic parameters [9]. According to Falola [7] and Gottschall [10], this muscle activity is a compensation to minimize the risk of falls by increasing stability during the transition phases. These changes are correlated with the increase in weight, which causes changes in gait to reduce the risk of falls. The lack of consensus may be related to a large variability in gait strategies and different adaptations to pregnancy [8], [9], protocols varying in terms of the number of subjects, instrumentation, and pregnancy period, as well as a limited number of studies.

To the best of our knowledge, no study has evaluated the gait of the pregnant woman using the GAITRite or similar walkway, which is a reliable, valid, accessible and less expensive tool, as compared to opto-electronic motion analysis systems used in other studies [23]. For these reasons, its clinical potential is relevant for therapists.

Understanding gait adaptations during pregnancy in healthy women may contribute to better understanding of the falls and the installation of PRPP, and possibly lead to the development of strategies for its prevention or treatment during pregnancy.

The purpose of the study was to describe the evolution of spatial and temporal gait parameters during the four last months of pregnancy and in post-partum. Also, a comparison with nulliparous women was conducted to evaluate the changes at different speeds (preferred, fast and slow). The objective was to contribute to evaluate the effect of pregnancy on the biomechanics of walking pattern.

2. Materials and methods

Participants

Fifty-eight pregnant women aged between 25 and 41 years, with no history of foot, ankle or knee musculoskeletal pain, no pelvic girdle pain, no neuromuscular trauma or disease and no cardiovascular problems participated in this study.

The subjects were divided into 4 groups: (1) 6th month (25 to 28 amenorrhea gestational weeks), (2) 7th month (29 to 32 amenorrhea gestational weeks), (3) 8th month (33 to 36 amenorrhea gestational weeks) and (4) 9th month (37 to 41 amenorrhea gestational weeks).

There was a post-partum women group formed of nine subjects (16 weeks to 8 months after delivery). 59% of womens worked, 28% were inactive and 13% were students. For parity: 71% of womens had no children, 27% had one child and 2% had two or more children.

Table 1. Characteristics of pregnant women (PW), post partum (PP) and control group (CG). Mean (SD)

	Months	Number of subjects	Age (years)	Height (cm)	Mass (kg)	BMI (kg/m^2) before pregnancy	BMI (kg/m^2)	Weight gain (kg)
PW	6	8	26(1)	168(6)	72(9)	23(3)	25(3)	8(4)
	7	17	28(5)	165(6)	70(9)	22(3)	26(3)	11(3)
	8	23	30(6)	165(5)	73(10)	23(6)	28(6)	10(4)
	9	10	29(3)	165(7)	73(8)	19(7)	26(3)	
PP		9	31(6)	167(6)	74(19)		26(6)	
CG		23	27(5)	168(6)	63910)	22(3)		

The pregnant and post-partum participants were recruited via direct contact during pre- and post-natal gym classes

Twenty-three healthy nulligravidae women between 21 and 38 years agreed to take part in the study as control group (CG).

The characteristics of the sample are presented in Table 1. All subjects gave written informed consent prior to participation in the study approved by Ethical Committee of the ULB University Hospital (Hôpital Universitaire Erasme, ULB, Belgium). The recruitment of subjects took place between January 2009 and December 2011.

Materials

The spatial and temporal parameters of gait were measured using the GAITRite electronic walkway (GAITRite Gold, CIR Systems, PA, USA, length: 6.1 m, width: 61 cm). Embedded pressure sensors form a horizontal grid. As the subject walks over the carpet, the sensors enable collection of spatial and temporal gait parameters. Data is sampled at a frequency of 100 Hz. The walkway is connected to a PC by a serial interface cable. The spatial and temporal characteristics of gait are processed and stored using GAITRite GOLD, version 3.2b software.

Methods

Before performing the motor task, anthropometric data (age, gender, shoe size, weight and height) were recorded for each subject. The length of the lower limbs (from the anterior-superior iliac spine to the medial malleolus) was determined with a tape in dorsal decubitus.

The motor task consisted of 9 gait trials (3 at each speed). For each gait trial, between 5–10 steps were sampled and included in the analysis. A rest period was allowed between trials. First, the subject was invited to walk at her preferred speed.

Then, the subjects walked at fast and slow speed. The order of the trials was randomised by dice throwing. Each participant was invited to walk barefoot on the GAITRite walkway.

The instructions for fast speed were "walk as fast as possible. As if you would catch a bus" and the instructions for slow speed were "walk slowly. As if you were shopping".

To counter the methodological bias of acceleration and deceleration in gait, the participants started walking 2 m ahead of the walkway and finished the trial 2 m after the end of the walkway.

Data processing

The following dependent variables were analyzed: stride length (m), step length (m), step width (m), (as the perpendicular distance between the heel center of one footprint to the line of progression (line through two consecutive heel centers) of the opposite foot) and toe in/out (degrees) for spatial parameters and gait velocity (m/s, obtained by dividing distance travelled by ambulation time), stride velocity (m/s, obtained by dividing stride length by stride time), step time (s), gait cycle time (s), single support (% of gait cycle), double support (% of gait cycle), swing (% of gait cycle) and stance (% of gait cycle) for temporal parameters.

Statistical analysis

All statistical procedures were conducted using Statistica 5.0 software for Windows. To investigate normal distribution of data in the groups we used the Kolmogorov–Smirnov test. All scores were found to be normally distributed. As no significant right-left differences were observed, parameters for both sides were averaged.

An analysis of variance for repeated measures (ANOVA) was performed for comparison of all variables between the different speeds (within group factor) and groups (between groups factor) evaluated. When a significant effect was found, the LSD post hoc test was applied. The statistical level of significance was set at 0.05.

3. Results

Temporal Parameters

The results of temporal parameters are presented in Table 2.

Velocity – Cadence – Stride velocity

At each speed, women walked slower during pregnancy compared to the control group: –20% at preferred speed, –22% at fast speed ($p < 0.001$) and –12% at slow speed ($p = 0.017$). Cadence was reduced by 8 to 9% at preferred and fast speed ($p < 0.001$). During pregnancy, a significant evolution of velocity ($p = 0.032$, Fig. 1) and stride velocity ($p = 0.001$) was observed. These parameters decreased between the 6th and 7th months of pregnancy at slow speed ($p = 0.034$) and increased between the 8th and 9th months at fast speed ($p = 0.013$). Cadence was comparatively constant during pregnancy.

Table 2. Mean (SD) temporal parameters during pregnancy, post partum (PP) and for control group (CG)

	Speed	Months				*P* value	Pregnancy	PP	*P* value	CG	*P* value	
		6	7	8	9		Mean		Pregn. vs. PP		Pregn. vs. GC	PP vs. GC
Velocity (m/s)	Slow	0.8 (0.12)	0.65 (0.28)	0.7 (0.20)	0.79 (0.14)	0.032	0.71 (0.21)	0.8 (0.27)	0.138	0.81 (0.13)	0.017	0.881
	Pref	1.05 (0.12)	0.92 (0.17)	1 (0.13)	1.04 (0.2)		0.99 (0.16)	1.11 (0.14)	0.051	1.26 (0.13)	<0.001	0.021
	Fast	1.40 (0.08)	1.32 (0.31)	1.39 (0.18)	1.56 (0.23)		1.4 (0.24)	1.64 (0.21)	<0.001	1.76 (0.22)	<0.001	0.082
Stride velocity (m/sec)	Slow	0.8 (0.12)	0.68 (0.22)	0.79 (0.42)	0.79 (0.14)	0.154	0.76 (0.29)	0.82 (0.27)	0.445	0.8 (0.36)	0.029	0.494
	Pref	1.05 (0.12)	0.96 (0.19)	1 (0.12)	1.04 (0.2)		1 (0.16)	1.11 (0.14)	0.193	1.28 (0.16)	<0.001	0.058
	Fast	1.41 (0.08)	1.33 (0.31)	1.4 (0.18)	1.56 (0.24)		1.4 (0.23)	1.67 (0.19)	0.002	1.71 (0.25)	<0.001	0.613
Cadence (step/min)	Slow	84 (18)	76 (24)	84 (18)	90 (9)	0.064	83 (19)	86 (20)	0.446	88 (11)	0.068	0.650
	Pref	101 (12)	98 (12)	104 (10)	106 (15)		102 (12)	106 (7)	0.375	112 (8)	0.001	0.168
	Fast	120 (7)	120 (18)	125 (12)	134 (14)		124 (15)	131 (12)	0.099	135 (13)	<0.001	0.412
Step time (sec)	Slow	0.74 (0.16)	0.82 (0.22)	0.76 (0.17)	0.68 (0.07)	0.082	0.76 (0.17)	0.85 (0.35)	0.014	0.69 (0.09)	0.012	<0.001
	Pref	0.60 (0.08)	0.63 (0.09)	0.58 (0.06)	0.57 (0.08)		0.6 (0.08)	0.57 (0.04)	0.452	0.53 (0.04)	0.010	0.345
	Fast	0.50 (0.03)	0.51 (0.08)	0.49 (0.05)	0.45 (0.05)		0.49 (0.06)	0.46 (0.04)	0.442	0.45 (0.03	0.064	0.643
Cycle time (sec)	Slow	1.48 (0.31)	1.59 (0.37)	1.48 (0.32)	1.35 (0.15)	0.130	1.49 (0.32)	1.52 (0.44)	0.640	1.39 (0.18)	0.014	0.049
	Pref	1.21 (0.15)	1.25 (0.17)	1.17 (0.13)	1.15 (0.16)		1.2 (0.15)	1.14 (0.08)	0.367	1.07 (0.07)	0.003	0.276
	Fast	1 (0.06)	1.02 (0.14)	0.97 (0.10)	0.91 (0.11)		0.98 (0.11)	0.92 (0.08)	0.360	0.89 (0.07)	0.031	0.601
Swing (%)	Slow	38 (1)	37 (4)	37 (3)	37 (2)	0.284	(37 (3)	37 (5)	0.732	39 (1)	<0.001	<0.001
	Pref	39 (1)	38 (2)	39 (2)	39 (2)		38 (2)	39 (2)	0.108	41 (1)	<0.001	0.001
	Fast	41 (1)	40 (2)	41 (1)	41 (1)		41 (2)	41 (1)	0.179	43 (1)	<0.001	0.007
Stance (%)	Slow	62 (1)	64 (3)	63 (2)	63 (1)	0.370	63 (3)	63 (5)	0.477	61 (1)	<0.001	<0.001
	Pref	61 (1)	62 (2)	62 (2)	61 (2)		61 (2)	61 (2)	0.127	59 (1)	<0.001	<0.001
	Fast	59 (1)	60 (2)	59 (1)	59 (2)		59 (2)	59 (1)	0.180	57 (2)	<0.001	0.002
Single support (%)	Slow	38 (1)	38 (8)	36 (3)	37 (1)	0.702	37 (5)	37 (5)	0.744	39 (1)	<0.001	0.052
	Pref	39 (1)	38 (2)	39 (2)	39 (2)		39 (2)	39 (2)	0.353	41 (1)	<0.001	0.044
	Fast	41 (1)	40 (2)	40 (1)	41 (1)		41 (2)	41 (1)	0.402	43 (1)	<0.001	0.113
Double support (%)	Slow	24 (3)	30 (10)	29 (7)	27 (5)	0.200	28 (7)	30 (12)	0.433	22 (2)	0.001	<0.001
	Pref	22 (2)	24 (5)	24 (11)	23 (3)		24 (8)	22 (4)	0.321	17 (2)	0.001	0.023
	Fast	18 (1)	21 (7)	19 (2)	17 (2)		19 (4)	17 (2)	0.441	14 (4)	0.009	0.089

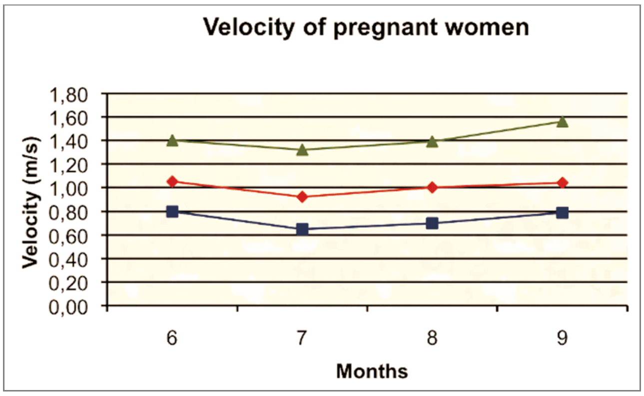

Fig. 1. Speed velocity
square: slow, diamond: preferred, triangle: fast

When pregnancy was compared with the post-partum period, there was no significant difference of velocity and cadence at preferred and slow speed. At fast speed, however, the pregnant women displayed reduced velocity (–15%) as compared to post-partum, despite absence of difference in cadence. After childbirth, a lower preferred gait velocity was seen (–12%), as compared to the control group ($p = 0.021$).

Step time – cycle time

Cycle time and step time were significantly longer in pregnant women compared to the control group. Cycle time increased to 7% at slow speed ($p = 0.014$), to 10% at preferred speed ($p = 0.003$) and to 9% at fast speed ($p = 0.031$). Step time increased to 8% at slow speed ($p = 0.012$) and to 11% at preferred speed ($p = 0.010$).

These two parameters remained relatively constant over the last 4 months of pregnancy and the post-partum period.

After childbirth, at preferred and fast speed, these parameters decreased to stabilize at values similar to the control group.

Swing and stance phase

The different phases of gait cycle were modified during pregnancy ($p < 0.001$). At each speed swing phase decreased: –2% and stance phase increased: +2% in comparison to the control group. Over the last four months of pregnancy no changes in gait cycle phases were found.

Swing and stance phase during post-partum remained similar to the pregnancy. However, for the difference between the values of post-partum with the CG for all speeds, we observed that the percentage remained shorter for swing phase during post-partum period: –2%. Therefore, the values of the stance phase remained longer: +2% ($0.007 < p < 0.001$).

Single and double support

The relative duration of single support during stance phase was significantly reduced (by 2%) during pregnancy as compared to the control group, whereas the double support phase was longer by 5 to 7%. Single and double support phases during post-partum did not significantly differ from pregnancy data. Nevertheless, after childbirth, the single support post-partum remained lower than in the CG at preferred gait: –2% ($p = 0.044$), whereas the double support was remained higher at slow and preferred speed: +8% ($p < 0.001$) to +5% ($p = 0.023$).

Spatial parameters

The results of spatial parameters are presented in Table 3.

Step and stride length

Pregnant women made smaller steps. The comparison between pregnant women and the CG revealed differences between 0.04 and 0.11 m, varying with speed and month of pregnancy ($p < 0.001$). Indeed, we observed a decrease between the 6th and 7th months of pregnancy ($p = 0.003$).

Similar results were obtained for stride length, which decreased by 0.08 to 0.23 m ($p < 0.001$) during pregnancy. From the 8th month, stride length gradually increased ($p = 0.004$).

Values during post-partum period were significantly higher than pregnancy data: by 8 to 11% for all speeds. However, after childbirth, the average step and stride lengths at preferred speed remained lower than in the control group (–0.05 m and –0.09 m).

Step width

The step width for pregnant women was increased by 1 to 2 cm, depending on walking speeds ($0.002 < p < 0.001$). In post-partum, values decreased to approach values observed in the CG.

Toe in/out angle

The angle between the line of progression and the middle of the footprint has increased between the 6th and 7th months of pregnancy, which indicates a significant opening of the step to the line of progression for all speeds ($p = 0.016$). The orientation of the foot of pregnant women was significantly different from the control group at preferential ($p = 0.003$) and fast ($p = 0.001$) speeds with an increase of the foot angle (1°) to the outside. However, after delivery, the angulation of the foot was similar to the period of pregnancy. The values of post-partum group were not statistically different from the control group.

Table 3. Mean (SD) spatial parameters during pregnancy, post partum (PP) and for control group (CG)

	Speed	Months				*P* value	Pregnancy	PP	*P* value	CG	P value	
		6	7	8	9		Mean		Pregn. vs. PP		Pregn. vs. GC	PP vs. GC
Step length (m)	Slow	0.58 (0.06)	0.5 (0.08)	0.49 (0.06)	0.52 (0.06)	0.003	0.51 (0.07)	0.55 (0.08)	0.006	0.55 (0.04)	<0.001	0.944
	Pref	0.62 (0.05)	0.56 (0.05)	0.56 (0.05)	0.58 (0.05)		0.58 (0.06)	0.62 (0.06)	0.002	0.67 (0.05)	<0.001	0.007
	Fast	0.7 (0.03)	0.65 (0.07)	0.66 (0.03)	0.69 (0.12)		0.67 (0.05)	0.75 (0.07)	<0.001	0.78 (0.06)	<0.001	0.139
Stride length (m.)	Slow	1.16 (0.12)	1.01 (0.15)	1.0 (0.11)	1.04 (0.12)	0.004	1.03 (0.14)	1.11 (0.17)	0.013	1.11 (0.09)	0.001	0.881
	Pref	1.26 (0.11)	1.13 (0.10)	1.15 (0.06)	1.16 (0.1)		1.16 (0.09)	1.26 (0.12)	0.002	1.35 (0.1)	<0.001	0.004
	Fast	1.41 (0.06)	1.31 (0.14)	1.33 (0.07)	1.37 (0.11)		1.34 (0.1)	1.53 (0.13)	<0.001	1.57 (0.12)	<0.001	0.201
Step width (m)	Slow	0.08 (0.03)	0.11 (0.02)	0.11 (0.04)	0.10 (0.03)	0.336	0.10 (0.03)	0.07 (0.03)	<0.001	0.08 (0.03)	<0.001	0.032
	Pref	0.09 (0.03)	0.1 (0.02)	0.11 (0.03)	0.10 (0.03)		0.10 (0.03)	0.09 (0.03)	0.003	0.08 (0.02)	<0.001	0.382
	Fast	0.08 (0.02)	0.09 (0.02)	0.10 (0.03)	0.10 (0.03		0.10 (0.03)	0.08 (0.03)	<0.001	0.09 (0.03)	0.002	0.168
Toe in/out (degrees)	Slow	–0. (4)	6 (6)	5 (5)	6 (3)	0.016	5 (6)	5 (4)	0.595	4 (5)	0.113	0.608
	Pref	–0. (2)	5 (4)	4 (5)	6 (2)		4 (4)	4 (4)	0.890	3 (5)	0.003	0.076
	Fast	–0. (2)	4 (5)	3 (4)	4 (3)		3 (4)	1 (3)	0.005	2 (4)	0.001	0.674

4. Discussion

In this study, the evolution of spatial and temporal gait parameters during the last four months of pregnancy was analysed and compared to observations of post-partum and non-pregnant control women.

During pregnancy

Pregnant women walked slower (0.99 (0.16) m/sec at preferred speed) compared to nulliparous women (1.26 (0.13) m/sec). There was a decrease of 22% at preferred speed and of 20% at fast speed. The results of CG are similar to those found in the study of Foti [9] with values of 1.2 (0.2) m/s for the pregnant woman.

In our study, women had an average gain of 10.3 kg or 14% during their pregnancy.

This decrease in speed may be correlated with the increase in body mass, as the maximum weight increase occurs during the last trimester.

However, in our study we found no correlation between gait speed and weight gain during pregnancy ($r = 0.03$), although weight accuracy cannot be guaranteed, as women verbally indicated their weight during the experimental session.

Holt [11] showed that the speed freely chosen corresponds to the energetically optimal gait and provides maximum stability. There is a strong relationship between the cost and speed gait.

For Falola [6] carrying an external load on the trunk results in an increase in energy cost and a disturbance of gait characteristics by increasing variability. All of these parameters lead to faster fatigue. The increase in abdominal mass of pregnant women creates a disturbance, which results in instability during gait. Thus, pregnant women decrease the optimal speed gait but do not spontaneously choose a pattern gait at lower energy cost, preferring to choose a safe gait associated with greater stability.

In addition, several authors [4] have shown that greater local stability is correlated with slower walking speed. However, a slower gait leads to greater variability of gait parameters, which implies a deterioration of stability [4]. The authors suggest that patients who have a risk of falls walk slowly: neuromuscular gait control systems can accommodate a slight increase in variability at slow speed in exchange for improved stability. We know that the risk of falls is important in pregnant women: 27% of women fall during pregnancy and 61.4% of the falls occur during the second quarter [10].

The cadence decreased by 9 % during pregnancy and stride length by 13% at preferred and by 14% at fast speed. It has been demonstrated, in young as well as in elderly people, that a shorter step length reduces the risk of falls [5]. This justifies the approach chosen by the pregnant woman who wants to maintain a safe gait and avoid falls. These results corroborate the study of Foti [9], Branco [2] and Forczek [8]. As a result, cycle time was increased in pregnant women with mean values of 1.20 (0.04) sec at preferred speed against 1.07 (0.07) sec for the GC. This difference was significant for all speeds. Similar differences were found for step time. However, the study of Branco [2] did not find a significant difference for these two parameters between pregnant women and a GC.

Pregnant women were characterized by a decrease in swing phase duration (–2%) and an increase in stance phase (+2%), probably aiming at minimizing instability. Pregnant women strive to maintain a safe gait. This may also be the cause of the alterations found for single and double support times: pregnant women decreased the single support phase (–2%) and increased the double support (+5 to +7%) at all speeds. The results of our study were comparable to those found in the literature [2], [9]. The period of double support may be unstable: the center of gravity moves to project under the heel of the supporting leg. Thus, during this period a lateral displacement of the center of gravity occurs. This action is carried out with the maximum security to avoid falls. Thus, pregnant women increase the duration of this transition to optimize time and strength to swing their body on one leg and to compensate the increase in size. Indeed, the lateral displacement of the center of pressure between each step increases during pregnancy by 0.17 m in early pregnancy to 0.35 m in late pregnancy. This corresponds to a 50% increase [18]. According to Mc Crory [17], the medio-lateral displacement of the center of gravity increases especially during the third trimester of pregnancy. This is certainly why the medio-lateral reaction forces are higher in late pregnancy [18].

Foti [9] proposes a complementary hypothesis to the previous one: the reduction of single support time can be a system of compensation to minimize the time spent in single support: a period marked by high muscle recruitment to support the body weight on one leg [9]. Our results confirm the reduction of single support and increase of double support times in pregnant women.

From the 7th month of pregnancy, pregnant women increase step angle outwards (+5°). This change may be related to the widening of the pelvis that could cause an increase in hip external rotation, which consequently would place the feet outward.

Gait of pregnant women is often described with a specific pattern that improves stability: the waddling gait, which comprises an increase of step width, of the external angle of the foot, and a tilt and rotation of the pelvis [9]. The first two parameters have also been identified in this study.

The stability control declines during pregnancy and remains low for 6–8 weeks after delivery. Butler [3] observed an increase of the dependence to visual cue to maintain balance during pregnancy. This balance can be measured through step width. A strong correlation is present between these parameters ($r = 0.94$) [12].

In our study, step width averaged 0.10 (0.08) m in pregnant women. This corresponds to an increase of 2 cm (15%) compared to nulliparous women. Our results corroborate Forczek's study [8] with a step width of 2 cm, Lymbery [16] with a step width of 2 cm and Jang [12] with a step width of 2.7 cm.

Foti [9] reported a significant increase in both the width of the pelvis and ankles of pregnant women. This ratio of the support base remains constant throughout pregnancy, aiming at guaranteeing the security and stability. Thus, the probability of moving the projection of the center of gravity outside the support base is minimized.

Postural oscillations are much more important during the second trimester than during the third trimester of pregnancy: stability is improved during the third trimester when the decrease of oscillations indicates an increase in postural rigidity with high risk of falls [17]. According to Jang [12], anteroposterior postural displacement increases during pregnancy and decreases in post-partum. In contrast, medial-lateral displacements remain relatively constant during pregnancy but tend to increase after delivery: this transverse stability is maintained by an increase in stance width and foot angle. The center of pressure (COP) is strongly altered laterally with an increase in its movements, while COP moves less in the antero-posterior plane, which can be explained by the increase in stance width. The reaction forces in the antero-posterior plane tend to have lower variability, while in the medio-lateral plane, there is a significant intra-variability, suggesting more adjustments in the frontal plane [16].

During the last 4 months of pregnancy

When comparing women at different stages of pregnancy, we observed a highly significant decrease of slow gait velocity and step length between the 6th and 7th month.

In his study, Falola [7] observed a significant decrease by 11% in walking speed between the 2th and 9th month of pregnancy. In our study, the decrease in slow speed between the 6th and the 7th month was 19%.

In our study, women have a weight gain of 11 (3) kg in the seventh month, which corresponds to the largest weight gain. As mentioned above, the decrease in speed is correlated with body mass. In our study, cadence remained relatively stable, while in Falola's study [7], a significant decline was reported from the 4th month (–18%).

For Branco [2], the temporal gait parameters (cycle time, step time, stance and swing time) are influenced by pregnancy but there is no significant difference between the 2nd and 3rd trimester of pregnancy: most parameters remain unchanged.

In post-partum

After childbirth, the woman maintained a natural walking speed (1.11 (0.14) m/sec) and cadence (106 (7) step/min) relatively similar to that obtained during pregnancy. Post-partum gait velocity remained slower than that of the control group (–12%). Swing phase (–2%) and single support (2%) remained shorter compared to the control group. At preferred gait, single support time remained lower (–2%) in post-partum and double support remained longer (+5%). These results confirm those of the study by Forczek [8], gait parameters returned to pre-pregnancy values within approximately 6 month after delivery, which is the time required to completely reduce the weight and dimensions of women. The results of the present study are comparable, as, on average 6 months postpartum, gait parameters were close to that of the CG. Indeed, several weeks do not seem sufficient to restore normal gait pattern [16]. After childbirth, women decreased step width to normal values.

This quantified the differences between the gait of pregnant women, of women after childbirth and nulliparous women in a large sample. Although some comparisons with previous studies could be made, it remains difficult to compare the absolute values of each study. The main reason is the variable gait velocity used in different studies. This parameter influences the kinematic as well as spatial and temporal parameters of gait [8].

The dominant strategy adopted by pregnant women maximizes safety and stability with lower energy cost during walking [8]. From a biomechanical point of view, pregnant women increase precautions in a similar way than elderly persons do. Thus, gait characteristics in pregnancy include a slower walking speed, small steps, increased double support time and an increase in gait variability, as reported in advanced age [14]. The modification of gait is a consequence of weight gain and weight distribution. However, there is no association between changes in postural control and weight changes, suggesting that other factors, such as increased ligament laxity, influence postural control [3]. Moreover, according to Foti [9], there are several alterations of kinetic parameters, such as an overuse of several muscle groups, during pregnancy that reflect compensation means to maintain a “normal” gait, despite an increase in body mass and anterior displacement of the center of gravity.

This work is a preliminary study to constitute a database on gait parameters in healthy pregnant women that can be used as normative data in clinical settings and studies. Examples of potential applications concern the impact of pregnancy-related pelvic or lumbar pain on gait. Such information could lead to the optimisation of prevention and rehabilitation strategies during pregnancy.

Limitations of the study

Recruitment was carried out in the obstetrics department of a University Hospital, which may bias the recruitment of our sample. Women who participated in the study were followed in the hospital and not in private gynecology practice, which suggests that the sample consists of a specific category of women, in terms of socioeconomic status or pregnancy evolution.

Postpartum women were recruited between 4–8 months after delivery. This is a relatively large interval. Therefore this group is heterogeneous and results concerning postpartum data should be considered with care.

Furthermore, it was not feasible to set up a longitudinal study, which would have allowed for a more detailed analysis of the evolution of gait during pregnancy. In this context, the analysis of only spatiotemporal gait parameters may appear as limiting. However, our work shows that their contribution is relevant and feasible in terms of acquisition in clinical routine.

Finally, in this study, the normal evolution of spatio-temporal gait parameters with pregnancy was investigated, neglecting the influence of several known factors, such as gait velocity and anthropometry. It could be of interest to extend the analysis to include normalization of gait parameters to velocity, lower extremity length, and corpulence, for instance.

5. Conclusion

The pattern of gait was significantly modified during pregnancy. Pregnant women’s gait was significantly different from that of nulliparous women. Pregnant women walk slower with a lower cadence and smaller step. Moreover, the phase pattern of gait was modified with a decrease of swing and single support phases and an increase of stance and double support. Step width was increased during pregnancy. All these changes favour a safer and more stable gait.

After childbirth, the characteristics of pregnancy gait remained partially present: slower gait speed, smaller steps, decreased swing phase and increased stance phase. At preferred speed, double support remained higher and single support lower.

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