Journal of Biomechanics 47 (2014) 2964–2968

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

The pregnant "waddle": An evaluation of torso kinematics in pregnancy

Jean L. McCrory [a,b,*], April J. Chambers [c], Ashi Daftary [d], Mark S. Redfern [c]

[a] Division of Exercise Physiology, Department of Human Performance and Applied Exercise Science, West Virginia University, Morgantown, WV, USA
[b] Department of Health and Physical Activity, University of Pittsburgh, Pittsburgh, PA, USA
[c] Department of Bioengineering, University of Pittsburgh, Pittsburgh, PA, USA
[d] West Penn Allegheny Health System, Pittsburgh, PA, USA

ARTICLE INFO

Article history:
Accepted 13 July 2014

Keywords:
Gait
Trimester
Walking
Pregnancy
Kinematics
Range of motion

ABSTRACT

Although pregnant women are anecdotally said to "waddle" during gait, researchers have not quantified the kinematics of these gait alterations. The **purpose** of this study was to examine the effects of pregnancy on thoracic and pelvic kinematics during gait.
Methods: Data were collected on 29 pregnant subjects in the mid-second and third trimesters and on 40 control women. Three-dimensional kinematic data were collected on subjects walking at their freely-chosen speed. Right foot heel-strike (RHS) and left foot toe-off (LTO) were determined from force plate data. Thoracic and pelvic angles at RHS, step width, mediolateral translation of the C7 and L4 vertebrae, and the ranges of motion (ROMs) of the thorax and pelvis over the gait stride were determined. A series of MANCOVAs were performed with trimester (second, third, and control) as the independent variable and velocity as the covariate ($\alpha = 0.05$). Post-hoc analyses were performed when appropriate.
Results: Increased lateral translation of the C7 and L4 vertebrae (third trimester > second trimester > control, $p < 0.05$) was noted, accompanied by an increased step width in the third trimester ($p = 0.03$). At heel strike, pregnant women had greater thoracic extension (third trimester > second trimester > control, $p < 0.05$) and greater anterior pelvic tilt (third trimester > control; $p < 0.05$). Sagittal plane thoracic ROM was less in the third trimester compared to controls ($p < 0.01$).
Conclusions: Pregnant women demonstrated a lateral shifting of the body during gait, which accompanied a greater step width. The increased thoracic extension and anterior pelvic tilt, along with decreased sagittal plane ROM are likely adaptations to increased abdominal size.

1. Introduction

Numerous anatomical and physiological changes occur during pregnancy, including substantial weight gain (Dumas et al., 1995), increased abdominal volume (Loftis et al., 2008), decreased abdominal muscle strength (Gilleard and Brown, 1996), and increased lumbar lordosis (Dumas et al., 1995). Because more than 50% of pregnant women report back pain (Dumas et al., 1995; Ostgaard et al., 1996), research on the biomechanics of the torso is warranted.

The effect of pregnancy on biomechanics of the torso during activities of daily living has been studied. Gilleard et al. reported no significant effect of pregnancy on thoracic or pelvic posture during sitting and standing (Gilleard et al., 2002b), although the thorax was less extended and the pelvis less anteriorly-tilted in post-partum during standing (Gilleard et al., 2002b). They also reported pregnancy-associated reductions in passive sagittal and transverse plane ranges of motion (ROM) but no change in trunk lateral flexion (Gilleard et al., 2002a).

Several authors have attempted to quantify the 'waddling' gait exhibited during pregnancy (Foti et al., 2000; Gilleard et al., 2008; Gilleard, 2013), although they have not been completely able to describe how pregnant-gait differs from non-pregnant gait. An increased step width (Bird et al., 1999; Foti et al., 2000; Gilleard, 2013) and decreased step length (Gilleard, 2013) occur in pregnancy. Foti et al. reported an increased anterior pelvic tilt in late pregnancy compared to post-partum (Foti et al., 2000). Women in their second trimester display less axial rotation of the thorax and pelvis during gait as well as a slower gait compared to nulliparous women (Wu et al., 2004a). Large inter-individual standard deviations were reported in the 3D ROMs of the pelvis and thorax

* Correspondence to: Division of Exercise Physiology, Department of Human Performance and Applied Exercise Science, 8315 HSC-South, PO Box 9227 Morgantown, WV 26506-9227. Tel.: +1 304 293 0442; fax: +1 304 293 7105.
E-mail address: jlmccrory@hsc.wvu.edu (J.L. McCrory).

http://dx.doi.org/10.1016/j.jbiomech.2014.07.009
0021-9290/

(Bird et al., 1999; Foti et al., 2000; Wu et al., 2004a). It is likely that statistical significance was not achieved between pregnant women and controls in several studies because of these large standard deviations. Recently, Gilleard performed a repeated measures analysis of thorax and pelvis movement patterns collected over the course of pregnancy (Gilleard, 2013). She reported decreases in pelvic rotation and obliquity as the pregnancy progressed; however, no alterations in thoracic movement were noted (Gilleard, 2013).

Pregnant women are more likely than non-pregnant women to experience low back pain (Dumas et al., 1995; Ostgaard et al., 1996; Wu et al., 2004b). Gait analyses in non-pregnant individuals with back pain reveal increased pelvic axial rotation compared to those without back pain (Seay et al., 2011). Wu et al. reported increased axial movement of the pelvis in pregnant women with low back pain; however, due to large inter-subject variability and a small sample size ($n=12$), statistical significance was not reached (Wu et al., 2008). Conversely, Gilleard et al. reported women in late pregnancy exhibited decrease pelvic rotation (Gilleard, 2013). Further research is warranted to explore if thoracic and pelvic movement kinematics during pregnancy are similar to other populations with back pain.

The concept of “waddling gait” and pregnancy-associated alterations to trunk biomechanics are not well understood. The purpose of this study was to examine the effects of advancing pregnancy on thorax and pelvis mechanics during gait. Given that pregnant women are said to “waddle” during gait, we hypothesized that mediolateral movement of the C7 vertebra would be increased in advanced pregnancy. We also hypothesized that frontal plane lateral lean of the thorax and pelvis would be increased in the third trimester. Given the increasing abdominal volume that accompanies pregnancy, we hypothesized that the thorax would become more extended throughout pregnancy and that the pelvis would demonstrate a greater anterior tilt. Finally, given that the majority of pregnant women experience back pain, and that other populations with back pain demonstrate increased pelvic rotation, we hypothesized that pregnant women would have increased pelvic transverse plane rotation.

2. Methods

2.1. Subjects

Forty-one pregnant women and forty non-pregnant controls participated. Subject demographics are shown in Table 1. Pregnant subjects and controls were matched to within 2 kg/m^2 BMI, based on the pregnant subjects' self-reported pre-pregnancy mass. Twenty-seven pregnant women were primigravid, while five were in their second pregnancy and nine were in their third pregnancy. Thirty-three controls were nulliparous. Six controls had been pregnant once, and one control had been pregnant twice.

Pregnant subjects were recruited through the UPMC Womancare Research Registry. Non-pregnant controls were recruited via advertisements placed around the community. Inclusion criteria for the pregnant group included: age 18–45 years and a low-risk pregnancy. Exclusion criteria for either group included: lower extremity fracture within five years or sprain within the last year, knee pain, history of diabetes or any other condition which could affect sensation, or history of lower extremity ligament rupture. Subjects were also excluded if they currently smoked, took any medication which would affect gait or balance, or had an average consumption of more than one alcoholic drink per day. Additional exclusion criteria for pregnant women included gestation beyond the twentieth week, current multiple gestation, or a history of delivery of an older child prior to 36 weeks of gestation, toxemia, gestational hypertension, pre-eclampsia, or gestational diabetes.

Data were collected on the pregnant subjects in the middle of their second trimester (20.9 ± 1.2 weeks) and third trimester (35.8 ± 1.5 weeks). Controls participated in a single data collection session in the week following menses. Twelve pregnant women withdrew from the study prior to their third trimester testing session because of pregnancy complications ($n=2$), premature delivery ($n=4$), injuries from a fall required bed-rest ($n=1$), relocation away from the area ($n=1$), and decision not to participate in third trimester testing session ($n=4$). Data from these women are not included in this study.

Table 1
Subject demographics (mean ± standard deviation).

	Control group ($n=40$)	Pregnant group ($n=29$)	
Age (yrs)	26.5 ± 6.4	29.5 ± 4.9	
Height (cm)	165.8 ± 5.6	166.1 ± 6.6	
		Second trimester	**Third trimester**
Weeks pregnant		20.9 ± 1.2	35.8 ± 1.5
Mass (kg)[a]	64.7 ± 8.8	73.9 ± 9.9	81.3 ± 11.1

[a] Subject mass was significantly different between the control group and each of the trimesters ($p < 0.001$). Age and height were also not significantly different between groups ($p > 0.05$).

2.2. Procedures

Data collection occurred at the Human Movement and Balance Laboratory on the campus of the University of Pittsburgh. Upon arrival in the lab, experimental procedures were explained. Written informed consent was then obtained in accordance with the procedures of the University Institutional Review Board.

The subject wore a close-fitting t-shirt, shorts, and comfortable walking shoes. Height and weight were determined with a medical scale and stadiometer. Spherical retro-reflective markers were placed on the subject in accordance with a modified Helen Hayes marker set. Specifically, the thorax was represented by markers placed on the manubrium of the sternum, xyphoid process, and markers placed on the C7 and T10 vertebrae. The pelvis was modeled by markers on the bilateral anterior and posterior superior iliac crests (ASIS and PSIS, respectively). Additionally, a marker was placed on the L4 vertebra. To determine step width, one marker was placed on the posterior aspect of each heel. A static calibration trial was collected with the subject standing with her feet shoulder width apart and shoulders abducted to 90°.

The coordinate systems for the thorax and pelvis were defined according to the modified Helen Hayes method. Specifically, the origin of the thorax coordinate system was the marker on the manubrium of the sternum. The z-axis, pointing upward, was calculated as the midpoint of the xyphoid process and T10 markers to the midpoint of the manubrium and C7 markers. The x-axis, pointing forward, was calculated as the midpoint of the C7 and T10 markers to the midpoint of the manubrium and xyphoid process markers. The y-axis was defined as the cross-product of the z-axis and x-axis. The origin of the pelvis coordinate system was the midpoint of the left and right ASIS markers. The y-axis was determined from the right ASIS to the left ASIS. The x-axis was calculated as the midpoint of the bilateral PSIS markers to the midpoint of the ASIS markers. The z-axis, which pointed superiorly, was the cross-product of the x-axis and the y-axis.

Each subject practiced walking along the 8-m runway in the laboratory to establish her freely chosen walking speed. An 8-camera motion capture system was used to collect 3D kinematic data (Version: Workstation, VICON Corp., Centennial, CO, USA). Kinematic data were collected at 120 Hz and filtered using a Woltring Filter with a MSE of 20. Two force plates concealed within the laboratory floor (Type 4060, Bertec Corp, Columbus, OH, 1080 Hz) were used to collect the sequential right foot then left foot ground reaction forces. From these forces, the times of right foot heel strike (RHS) and left foot toe off (LTO) were determined. At least five good trials were collected of each subject. A trial was termed “good” if the subject struck the force plates with no visible alteration to gait mechanics.

The following variables were calculated from each trial: frontal, sagittal, and transverse positions of the thorax and pelvis with respect to the laboratory coordinate system at RHS, frontal, sagittal, and transverse plane ROMs of the thorax and pelvis between RHS and LTO, and frontal plane ROM only of the C7 and L4 markers between RHS and LTO. Sagittal plane thoracic and pelvic orientations with respect to the lab coordinate system were termed thoracic flexion/extension and anterior/posterior pelvic tilt, respectively. Frontal plane thoracic and pelvic orientations with respect to the lab coordinate system were termed thoracic lean and pelvic obliquity. Transverse plane orientations of the thorax and pelvis with respect to the lab coordinate system were called thoracic and pelvic rotations. Orientations of the thorax and pelvis were calculated with respect to the static trial. Step width was calculated as the mediolateral distance between the heel markers at RHS. Walking velocity was calculated as the average velocity of the L4 marker between RHS and LTO. Each of the calculated variables from the five trials per subject were averaged to yield a representative value for each subject.

The results for walking velocity between the trimesters were reported in a previous article (McCrory et al., 2011). Control subjects (1.47 ± 0.13 m/s) walked faster than subjects in their second trimester (1.34 ± 0.15 m/s), who in turn walked faster than women in their third trimester (1.28 ± 0.16 m/s) ($p < 0.05$, (McCrory et al., 2011)).

2.3. Statistical analyses

An ANOVA was used to analyze the demographic variables of age, height, mass, and walking velocity. The independent variable in our statistical analyses was trimester (control, second trimester, third trimester). The 3D kinematic variables were collected in the same trials and were not considered statistically independent; therefore, a multivariate analysis of covariance (MANCOVA) was performed. Because walking velocity was significantly different between trimesters and because it can affect trunk mechanics (Wu et al., 2004a), it was a covariate in each analysis. First, a MANCOVA was performed to compare frontal plane translation of the C7 and L4 markers as well as step width between trimesters. Secondly, frontal, sagittal, and transverse plane positions of the thorax and pelvis at RHS were compared between trimesters with a MANCOVA. Finally, MANCOVA was performed to compare frontal, sagittal, and transverse plane ROMs of the thorax and pelvis between RHS and LTO between trimesters. The alpha-value for each comparison was 0.05. Tukey post-hoc analyses were performed when appropriate ($\alpha = 0.05$).

3. Results

Frontal plane translations of the C7 and L4 markers were significantly different between trimesters (both p values=0.001), with post-hoc analyses revealing that the motion was greater during the third trimester than during the second trimester, which was in turn greater than in controls (Fig. 1). Step width was greater ($p = 0.03$) in the third trimester (9.7 ± 3.9 cm) compared to the second trimester (8.4 ± 3.4 cm) and the controls (8.7 ± 3.5 cm). Step width was not different between the second trimester and controls.

At heel contact, the thorax was more extended during the third trimester compared to the second trimester ($p = 0.001$). In addition, it was more extended in the second trimester compared the controls ($p = 0.01$; Fig. 2). The pelvis was more anteriorly tilted at heel strike in the third trimester when compared to controls ($p = 0.049$), although the position of the pelvis at heel strike in the second trimester was not different from the third trimester or controls. No other variables at the thorax or pelvis were different at heel strike between trimesters (Table 2).

The sagittal plane ROM of the thorax during the gait cycle was less in the third trimester than in the controls or in the second trimester (Table 2, $p = 0.009$). The sagittal ROM of the thorax was not different between controls and pregnant women in their second trimester. There were no other differences in the thorax or pelvis 3D ROMs during the gait cycle between trimesters (Table 2). Walking velocity was a significant covariate in thoracic frontal plane ROM during the gait cycle ($p = 0.001$).

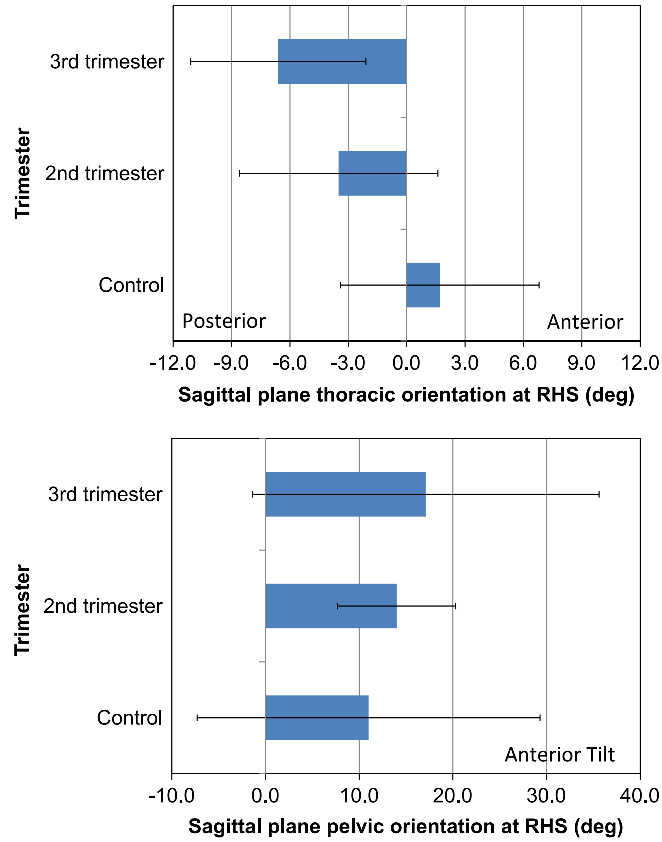

Fig. 2. Sagittal plane position of the (a) thorax and (b) pelvis at right heel strike. For the thorax, post-hoc analyses revealed significant differences between every level of trimester ($p < 0.05$). For the pelvis, post-hoc analyses revealed that the controls are significantly different from the third trimester ($p < 0.01$).

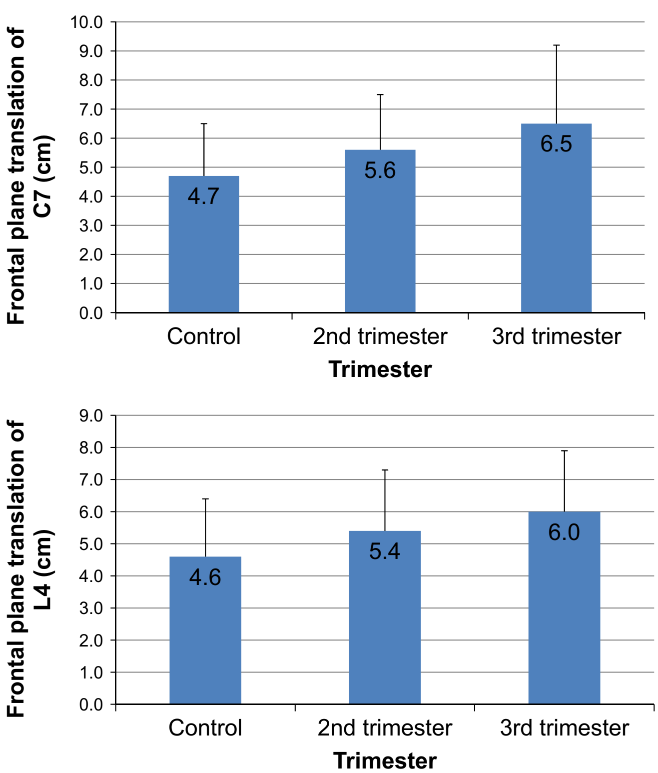

Fig. 1. Frontal plane range of motion of (a) C7 and (b) L4 during the gait cycle ($p < 0.01$). Post-hoc analyses revealed significant differences were noted between each of the trimesters and controls ($p < 0.05$).

4. Discussion

The purpose of this study was to examine the effects of advancing pregnancy on thorax (i.e. upper torso) and pelvis (i.e. lower torso) kinematics during gait. We hypothesized that frontal plane angular ROMs of the thorax and pelvis and that lateral translation of the C7 vertebra would be increased in the third trimester. Our results partially support these hypotheses. We found greater lateral movement of the trunk during each stride, but not greater angular rotation in the frontal plane.

Specifically, pregnant women in their third trimester demonstrated greater lateral translation of the trunk, as evidenced by greater side-to-side motion of markers placed on the C7 and L4 vertebrae during each stride. This greater trunk movement was accompanied by a greater step width in the third trimester. However, the frontal plane angular rotations, or lateral lean, of the thorax and pelvis during gait was not affected by pregnancy. Others have reported on pregnancy-related alterations to anterior pelvic tilt, axial rotation of the thorax and pelvis, and decreased pelvic obliquity during gait (Foti et al., 2000; Gilleard, 2013); however, to our knowledge, alterations to translational movements of the trunk, such as this side-to-side movement, have not previously been reported.

Table 2
3D kinematic variables (mean ± standard deviation) between trimesters during the gait cycle. P_T is the p-value for the between trimesters comparison. P_v is the p-value for velocity, the covariate in the analysis.

	Control	Second trimester	Third trimester	*p*-value
Position at heel contact				
Thorax				
Frontal plane (deg)	1.4 ± 2.4	0.8 ± 2.9	1.0 ± 2.4	P_T=0.72 P_V=0.05
Transverse plane (deg)	0.9 ± 3.4	2.0 ± 3.8	1.9 ± 4.0	P_T=0.06 P_V=0.17
Pelvis				
Frontal plane (deg)	4.1 ± 16.7	1.9 ± 3.1	3.6 ± 8.0	P_T=0.67 P_V=0.51
Transverse plane (deg)	−3.2 ± 17.0	−3.7 ± 4.3	−1.7 ± 16.0	P_T=0.43 P_V=0.77
ROM during the gait cycle				
Thorax				
Sagittal plane (deg)	5.8 ± 2.2	6.0 ± 2.7	5.0 ± 2.1	P_T=0.01 P_V= 0.40
Frontal plane (deg)	4.1 ± 1.9	4.5 ± 2.7	4.7 ± 2.7	P_T=0.95 P_V=0.01
Transverse plane (deg)	7.5 ± 2.4	7.6 ± 3.2	7.4 ± 2.2	P_T=0.82 P_V=0.76
Pelvis				
Sagittal plane (deg)	8.2 ± 3.5	8.7 ± 9.7	11.9 ± 12.1	P_T=0.23 P_V=0.18
Frontal plane (deg)	12.9 ± 3.8	11.2 ± 3.2	14.8 ± 12.5	P_T=0.22 P_V=0.83
Transverse plane (deg)	14.0 ± 8.1	12.7 ± 8.2	13.8 ± 19.3	P_T=0.72 P_V=0.06

The greater lateral movement of C7 and L4 in pregnancy is likely related to the concomitant increase in step width, but the specific mechanism for this change in movement pattern needs further investigation. It is believed that the increased step width is a consequence of the biomechanical adaptations to changing anthropometry during pregnancy, such as in obese individuals who exhibit increased step width as well as greater mediolateral displacement of the head during gait (Messier, 1994; Vartiainen et al. 2012). Alternatively, because 27% of pregnant women fall (Dunning et al., 2010), this increased step width may be associated with the increased risk of falling during pregnancy. Maki asserted that increased step width is predictive of falling in elderly individuals (Maki, 1997). Increased step width may destabilize the center of mass (COM) movement in the frontal plane, thus putting an individual at risk of falling (Rosenblatt and Grabiner, 2010; Singer et al., 2012). Schrager et al. reported concurrent increases in step width and mediolateral displacement of the COM in elderly individuals (Schrager et al., 2008), similar to what is seen in our pregnant population. They assert that this increased COM mediolateral translation is related to decreased lateral stability and increased fall risk (Schrager et al., 2008). Thus, the significantly greater lateral translation of C7 and T10 in the pregnant women in this study, which is related to the frontal plane movement of the COM, may be used to distinguish pregnant women who are at higher risk of falls. Others purport that an increased step width is a compensatory mechanism used by individuals at risk of falling to increase frontal plane stability (Chamberlin et al., 2005). Elderly individuals may increase step width as a means to increase their base of support and improve dynamic stability during gait (Chamberlin et al., 2005). Perhaps this increased step width is an adaptation used by pregnant women to increase stability during gait.

We hypothesized that the extended thorax that accompanies pregnancy would result in greater thoracic extension and anterior pelvic tilt during locomotion. Our results confirm this hypothesis. At heel strike, the controls were in a position of 1.7 ± 5.1° thoracic flexion, while pregnant subjects were in a position of 3.5 ± 5.1° thoracic extension in their second trimester and 6.6 ± 4.5° thoracic extension in the third trimester. Additionally, in their third trimester, pregnant subjects exhibited approximately 6° more anterior pelvic tilt at heel strike compared to controls.

These results are supported by the findings of others. Gilleard et al. stated that pregnant subjects displayed 4.5° greater thoracic extension and 13° greater anterior pelvic tilt during quiet standing when compared to post-partum (Gilleard et al., 2002b). In gait, Foti et al. reported 4° greater maximum anterior pelvic tilt during pregnancy compared to post-partum (Foti et al., 2000). However, Gilleard found no change in sagittal plane kinematics during gait as pregnancy progressed, although she noted large between-subject variability (Gilleard, 2013).

Large inter-subject variability is a commonly reported in most studies that assessed the biomechanics of pregnant gait (Bird et al., 1999; Foti et al., 2000; Gilleard et al., 2008; Gilleard, 2013; Wu et al., 2008). The gait analyses by Foti et al. (2000), Gilleard (2013), and Wu et al. (2008) had a much smaller number of subjects than the current study, with 15, 9, and 12 women participating, respectively, in each. Our study, which included 29 pregnant women and 40 controls, also found high levels of variability across subjects; however, the experiment had sufficient power to be able to find statistical significance in some variables of interest.

In our study, the increased variability is most noticeable at the pelvis. Gilleard reported decreased pelvic rotation during late pregnancy (Gilleard, 2013), but we did not. This is not surprising given the large amount of variability in the pelvic rotation across subjects in our study. This may indicate that adaptations to pregnancy are unique to each individual (Gilleard, 2013). An analysis of the within-subject variability in our participants is provided as Supplementary Data to this manuscript.

We reported decreased sagittal plane ROM of the thorax over the gait stride in the women in their third trimester of pregnancy when compared to their second trimester and to controls. Gilleard also reported a significantly less thoracic sagittal plane ROM during gait at 38 weeks compared to 24 and 32 weeks of pregnancy, as well as compared to post-partum and to nulliparous controls (Gilleard, 2013). It is likely that sagittal plane ROM is limited by the increased abdominal volume that occurs in the third trimester (Loftis et al., 2008).

More than 50% of pregnant women experience low back pain (Dumas et al., 1995; Ostgaard et al., 1996). Gait analyses on non-pregnant individuals with back pain reveal increased axial rotation of the pelvis compared to pain-free controls (Seay et al., 2011). However, we did not find increased pelvic rotation during pregnancy (Table 2). Given that we found increased thoracic extension and anterior pelvic tilt, pregnancy-associated back pain may instead be related to sagittal plane alterations. Additionally, we do not know how many of our subject experienced back pain and therefore we cannot compare those with back pain and those without pain.

The current study has some limitations. All of our markers were placed on bony prominences; however, in late pregnancy, those prominences were more difficult to palpate. Additionally, in other studies on gait alterations in pregnancy, pregnant subjects served as their own control during post-partum (Foti et al., 2000; Gilleard, 2013). We utilized a separate control group, but we tried to lessen the differences between the control and pregnant subjects by matching subjects on age and pre-pregnancy BMI. Thus, our comparisons within each trimester were between-subjects designed, while our comparisons between the trimesters were within-subject designed.

5. Conclusions

Pregnant women exhibit a “waddling” gait. This biomechanical pattern can be described as increased lateral motion of the trunk accompanied by a greater step-width in the third trimester, as well as increased sagittal plane extension of the thorax and increased anterior pelvic tilt.

These findings may be significant because of their relationship to back pain in pregnant women as well as the increased risk of falling during pregnancy. More than 50% of pregnant women experience back pain (Dumas et al., 1995; Vullo et al., 1996). The pregnant women in this study did not demonstrate the increased pelvic rotation exhibited by other populations with back pain; however, the increased thoracic extension and anterior pelvic tilt exhibited by our participants may create an increased lumbar lordosis that is related to back pain. Additionally, 27% of women fall while pregnant (Dunning et al., 2010). The pregnant women in this study demonstrated increased step width and lateral translation of the torso that is noted in other populations at risk of falling. Further research is necessary to determine if these measures may be predictive of falls in certain pregnant women.

Funding source

NIOSH K01 OH8548.

Conflict of interest statement

No author has any financial or personal relationship with other people or organizations that could inappropriately influence their work.

Acknowledgments

The authors would like to thank Kristen Berger and Leah Enders for their work on this project. We also are grateful to the UPMC Womancare Research Registry for allowing us to recruit the pregnant participants from its vast database.

This research was supported by NIOSH K01 OH8548. NIOSH had no involvement in the study design, data collection, analysis, and interpretation, or in the writing of this manuscript.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.jbiomech.2014.07.009.

References

Bird, A.R., Menz, H.B., Hyde, C.C., 1999. The effect of pregnancy on footprint parameters. A prospective investigation. J. Am. Podiatr. Med. Assoc. 89, 405–409.
Chamberlin, M.E., Fulwider, B.D., Sanders, S.L., Medeiros, J.M., 2005. Does fear of falling influence spatial and temporal gait parameters in elderly persons beyond changes associated with normal aging? J. Gerontol. A Biol. Sci. Med. Sci. 60, 1163–1167.
Dumas, G.A., Reid, J.G., Wolfe, L.A., Griffin, M.P., McGrath, M.J., 1995. Exercise, posture, and back pain during pregnancy. Clin. Biomech. 10, 98–103.
Dunning, K., Lemasters, G., Bhattacharya, A., 2010. A major public health issue: the high incidence of falls during pregnancy. Matern. Child Health J. 14, 720–725.
Foti, T., Davids, J.R., Bagley, A., 2000. A biomechanical analysis of gait during pregnancy. J. Bone Joint Surg.-Am. Vol. 82A, 625–632.
Gilleard, W., Crosbie, J., Smith, R., 2002a. Effect of pregnancy on trunk range of motion when sitting and standing. Acta Obstet. Et Gynecol. Scand. 81, 1011–1020.
Gilleard, W., Lai, D.T., Levinger, P., Begg, R.K., 2008. Detecting trunk motion changes due to pregnancy using pattern recognition techniques. Conf. Proc. IEEE Eng. Med. Biol. Soc. 2008, 2405–2408.
Gilleard, W.L., 2013. Trunk motion and gait characteristics of pregnant women when walking: report of a longitudinal study with a control group. BMC Pregnancy Childbirth 13, 71–78.
Gilleard, W.L., Brown, J.M.M., 1996. Structure and function of the abdominal muscles in primigravid subjects during pregnancy and the immediate postbirth period. Phys. Ther. 76, 750–762.
Gilleard, W.L., Crosbie, J., Smith, R., 2002b. Static trunk posture in sitting and standing during pregnancy and early postpartum. Arch. Phys. Med. Rehabil. 83, 1739–1744.
Loftis, K., Halsey, M., Anthony, E., Duma, S.M., Stitzel, J., 2008. Pregnant female anthropometry from ct scans for finite element model development. Biomed. Sci. Instrum. 44, 355–360.
Maki, B., 1997. Gait changes in older adults: predictors of falls or indicators of fear. J. Am. Geriatr. Soc. 45, 313–320.
McCrory, J.L., Chambers, A.J., Daftary, A., Redfern, M.S., 2011. Ground reaction forces during gait in pregnant fallers and non-fallers. Gait Posture 43, 524–528.
Messier, S.P., 1994. Osteoarthritis of the knee and associated factors of age and obesity: effects on gait. Med. Sci. Sports Exerc. 26, 1446–1452.
Ostgaard, H.C., Roos-Hansson, E., Zetherstrom, G., 1996. Regression of back and posterior pelvic pain after pregnancy. Spine 21, 2777–2780 (Phila Pa 1976).
Rosenblatt, N., Grabiner, M., 2010. Measures of frontal plane stability during treadmill and overground walking. Gait Posture 31, 380–384.
Schrager, M.A., Kelly, V.E., Price, R., Ferrucci, L., Shumway-Cook, A., 2008. The effects of age on medio-lateral stability during normal and narrow base walking. Gait Posture 28, 466–471.
Seay, J.F., Van Emmerik, R.E., Hamill, J., 2011. Influence of low back pain status on pelvis-trunk coordination during walking and running. Spine 36, E1070–E1079 (Phila Pa 1976).
Singer, J., Prentice, S., McIlroy, W., 2012. Dynamic stability control during volitional stepping: a focus on the restabilisation phase at movement termination. Gait Posture 35, 106–110.
Vartiainen, P., Bragge, T., Lyytinen, T., Hakkarainen, M., Karjalainen, P.A., Arokoski, J. P., 2012. Kinematic and kinetic changes in obese gait in bariatric surgery-induced weight loss. J. Biomech. 45, 1769–1774.
Vullo, V.J., Richardson, J.K., Hurvitz, E.A., 1996. Hip, knee, and foot pain during pregnancy and the postpartum period. J. Fam. Pract. 43, 63–68.
Wu, W.H., Meijer, O.G., Bruijn, S.M., Hu, H., van Dieen, J.H., Lamoth, C.J.C., van Royen, B.J., Beek, P.J., 2008. Gait in pregnancy-related pelvic girdle pain: amplitudes, timing, and coordination of horizontal trunk rotations. Eur. Spine J. 17, 1160–1169.
Wu, W.H., Meijer, O.G., Lamoth, C.J.C., Uegaki, K., van Dieen, J.H., PIJM, Wuisman, de Vries, J.I.P., Beek, P.J., 2004a. Gait coordination in pregnancy: transverse pelvic and thoracic rotations and their relative phase. Clin. Biomech. 19, 480–488.
Wu, W.H., Meijer, O.G., Uegaki, K., Mens, J.M.A., van Dieen, J.H., PIJM, Wuisman, Ostgaard, H.C., 2004b. Pregnancy-related pelvic girdle pain (PPP), I: terminology, clinical presentation, and prevalence. Eur. Spine J. 13, 575–589.