Gait & Posture 76 (2020) 204–209

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Torso kinematics during gait and trunk anthropometry in pregnant fallers and non-fallers

Jean L. McCrory[a,b,*,1], April J. Chambers[c,2], Ashi Daftary[d,3], Mark S. Redfern[c,2]

[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, Pittsburgh, PA, USA
[c] Department of Bioengineering, University of Pittsburgh, Pittsburgh, PA, USA
[d] West Penn Allegheny Health System, Pittsburgh, PA, USA

ARTICLE INFO

Keywords:
Gait
Fallers
Walking
Pregnancy
Kinematics

ABSTRACT

Background: Pregnant women experience numerous physiological and biomechanical alterations which may be associated with their increased risk of experiencing a fall. Gait alterations in other populations who fall include increased step width and mediolateral trunk motion. It is not known if pregnant women who have fallen exhibit these alterations.
Research question: Our purpose was to examine torso kinematics and step width during gait in pregnant fallers, pregnant non-fallers and non-pregnant controls. We also examined trunk anthropometry in the pregnant groups to determine if pregnant fallers have different trunk physiques than pregnant non-fallers.
Methods: 3D kinematic data were collected on 14 pregnant fallers, 15 pregnant non-fallers and 40 non-pregnant controls. Pregnant women were in their second or third trimester of pregnancy. Frontal plane translations of C7 and L4, step width, stride length, walking velocity, and 3D thoracic and pelvic kinematics were determined. Anthropometric torso measurements were obtained on the pregnant women. A series of MANCOVAs was performed (covariate: walking velocity, $\alpha = 0.05$) to compare the dependent variables between pregnant fallers, pregnant non-fallers, and controls. Tukey post-hoc analyses were performed when appropriate ($\alpha = 0.05$). A MANOVA compared anthropometric variables between pregnant fallers and non-fallers ($\alpha = 0.05$).
Results: Pregnant non-fallers exhibited greater step width and frontal and transverse plane angles at heel contact and range of motion over the gait cycle when compared to the fallers. Trunk anthropometry did not differ between pregnant fallers and non-fallers.
Significance: Pregnancy-associated gait alterations differed between fallers and non-fallers. Greater step width of the pregnant non-fallers increased the base of support, thus increasing stability. Exercise participation may allow pregnant women to better adapt to their altered physiques and be more able to prevent a fall should a trip or slip occur.

1. Introduction

Pregnant women are at increased risk of falling, as more than 27 % of pregnant women fall [1]. Falls are a primary cause of trauma-related hospital admissions during pregnancy [1], resulting in bone fractures, lacerations, joint sprains, muscle strains, head injury, placental rupture, and in severe cases, maternal and/or fetal death [2,3]. Anatomical and physiological alterations associated with pregnancy, such as weight gain [4], increased laxity in the peripheral joints in the arms and legs [5], increased thoracic curvature [6], increased spinal lordosis [7] decreased abdominal muscle strength [8], and decreased thoracopelvic coordination [9] may contribute to this increased fall risk.

The gait of pregnant women is characterized as having a wider stance-width [4,10], shorter stride length [11], increased anterior

* Corresponding author at: Division of Exercise Physiology, Department of Human Performance and Applied Exercise Science, 8315 HSC-South, PO Box 9227, Morgantown, WV 26506-9227, USA.

E-mail addresses: jlmccrory@hsc.wvu.edu (J.L. McCrory), ajcst49@pitt.edu (A.J. Chambers), daftarya@gmail.com (A. Daftary), mredfern@pitt.edu (M.S. Redfern).

[1] Division of Exercise Physiology, 8315 Health Sciences Center South PO Box 9227, Morgantown, WV, 26506-9220 USA.
[2] Human Movement and Balance Lab, 441 Benedum Hall, 3700 O'Hara Street, Pittsburgh, PA, 15260 USA.
[3] Department of Maternal-Fetal Medicine, West Penn Hospital, 4815 Liberty Ave, Pittsburgh, PA 15224, USA.

https://doi.org/10.1016/j.gaitpost.2019.11.012
Received 20 June 2019; Received in revised form 22 November 2019; Accepted 26 November 2019

Table 1
Subject Demographics (mean (standard deviation)).

	Control Group (n = 40)	Pregnant Group (n = 29)			
		Non-fallers (n = 15)		Fallers (n = 14)	
Age (yrs)	26.5 (6.4)	29.6 (5.1)		29.1 (4.9)	
Height (cm)	165.8 (5.6)	165.9 (6.5)		165.8 (6.2)	
		Second Trimester	**Third Trimester**	**Second Trimester**	**Third Trimester**
Weeks Pregnant		20.9 (1.4)	35.9 (1.7)	20.9 (1.1)	35.5 (1.3)
Mass (kg)	64.7 (8.8)	76.0 (13.6)	81.5 (11.0)	72.8 (9.9)	83.4 (11.6)

*Subject mass was significantly different between the control group and each of the trimesters ($p < 0.001$). Subject mass was not significantly different between pregnant fallers and non-fallers ($p = 0.421$). Age and height were also not significantly different between trimesters or fall group ($p > 0.05$).

pelvic tilt [12], decreased pelvic obliquity [13], and increased extension of the thorax [10,13]. Additionally, pregnant women have been reported to demonstrate either a greater lateral translation of the trunk [10] or lateral trunk lean [14] during gait. Wu et al. [9] and Gilleard [4] reported reductions in thoracopelvic ranges of motion (ROMs) in late-stage pregnancy. Sawa et al. [15] purported that in late pregnancy, women exhibit a decreased ability to control trunk movement in the anteroposterior direction. Gilleard et al. reported notable intersubject variability in trunk position in quiet stance [16] and biomechanics during gait [4]. These individual adaptations to the marked changes in trunk anthropometry during pregnancy have made generalizations challenging [4].

Several differences have already been noted between pregnant women who fell while pregnant and those who did not. Pregnant fallers exhibited a truncated response of the center of pressure in response to a fore-aft perturbation to quite stance [17], increased anteroposterior braking impulse during stair ascent, and a decreased propulsive peak force and propulsive impulse during descent [18]. It is notable that women who reported being sedentary while pregnant were significantly more likely to experience a fall compared to women who participated in some form of exercise [17]. Forczek et al. [11] noted beneficial lower extremity kinematic gait alterations in pregnant exercisers compared to sedentary women.

Other populations who fall, such as the elderly and individuals with neurological pathologies, demonstrate altered gait kinematics when compared to non-fallers. Elderly fallers exhibit greater step width [19,20] as well as greater mediolateral displacement of the trunk [21]. It is unknown if these changes are related to the cause of a fall or are adaptations made by the individuals to try to reduce fall-risk.

Pregnant women experience pronounced anthropometric changes to the trunk, including rapid increases in abdominal volume and weight, which may contribute to the increased fall-risk during pregnancy. Because there are limited data on pregnant fallers, studies on obese fallers may provide insight on alterations during pregnancy that place these women at an increased risk of falling, as healthy non-elderly, non-diabetic obese adults have a 20 % higher risk of experiencing a fall, and a 32 % higher risk of falling multiple times, compared to non-obese adults [22]. Older adults who reported falling within the past year had a significantly greater waist circumference than those who did not fall [23]. It is not known if physical parameters differ between pregnant fallers and non-fallers; thus, an examination of trunk anthropometry is warranted.

The purpose of our study was to determine if pregnant fallers exhibit altered thoracopelvic kinematics and step width during gait compared to pregnant non-fallers and non-pregnant women. A secondary purpose was to compare trunk anthropometry between pregnant fallers and non-fallers to examine if physical trunk characteristics help explain any movement patterns differences noted between these two groups. Given that we have previously found increased mediolateral trunk translation with advanced pregnancy [10] and that other populations who fall exhibit increased frontal plane movement of the torso and greater step width [19,21], we hypothesized pregnant fallers would demonstrate increased mediolateral motion of the C7 and L4 vertebrae, greater frontal plane angular thoracic and pelvic ROMs and a greater step width. Additionally, we hypothesized that pregnant fallers would exhibit greater mass gain in pregnancy and greater waist circumference compared to pregnant non-fallers.

2. Methods

2.1. Subjects

Forty one pregnant women and 40 non-pregnant controls participated. Data were collected on the pregnant women in their second (n = 41) and third trimesters (n = 29) and on the control women immediately following menses. Twelve pregnant subjects withdrew from the study prior to their third trimester visit for the following reasons: pregnancy complications (n = 2), preterm delivery (n = 4), decision to not participate (n = 4), relocation away from area (n = 1), and complications from a fall required bed-rest (n = 1). Their data are not included in this analysis. Control women were matched to pregnant women based on self-reported pre-pregnancy BMI $\pm$ 2 kg/m^2. Subject demographics are shown in Table 1.

Potential participants were excluded if they were not between ages 18 and 45 years, were a current smoker, experienced a lower extremity sprain within the past year or fracture within the last five years, or if they had a history of lower extremity ligament rupture. Other exclusion criteria included history of neuropathy, current use of any medication which could alter gait or balance, or consuming more than one alcoholic drink per day. Pregnant participants were also excluded if they were multigravidas, were beyond the 20^{th} week of pregnancy, had delivered an older child prior to 36 weeks gestation, or if their physician considered their pregnancy to be high-risk.

2.2. Procedures

Data collection took place in the Human Movement and Balance Laboratory at the University of Pittsburgh. On each participant's initial visit, experimental procedures were explained. Each participant read and signed an informed consent document that was approved by the university IRB. Following this, she was supplied with a close-fitting t-shirt and spandex shorts. Subjects wore lace-up athletic shoes during the testing. Height and mass were obtained using a standard medical scale and stadiometer. To obtain mass, the subject stood barefoot facing away from the scale while mass to the closest 0.1 kg was recorded with the balance bar centered between the upper and lower guides. Height to the nearest 0.1 cm was taken with the stadiometer arm in a level position and in contact with the superior posterior portion of the skull.

At each study visit, pregnant subjects were surveyed about their history of falls during this pregnancy. Pregnant subjects were also contacted to determine if they fell after their third trimester study visit prior to giving birth. A fall was defined as a loss of balance such that another part of the body other than a foot touched the ground. Additional details about the falls reported by the pregnant fallers are

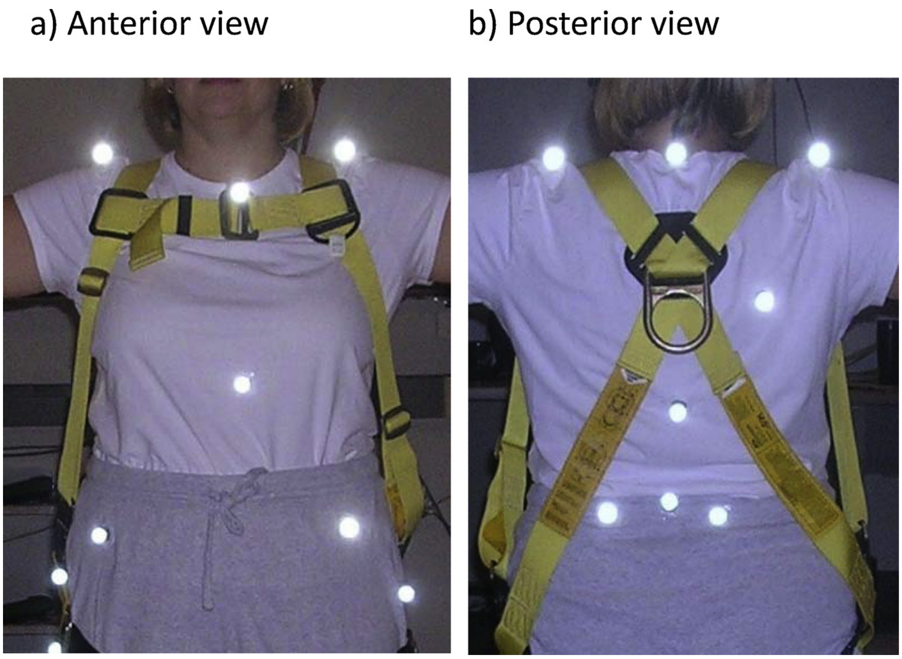

Fig. 1. Marker locations from the Plug-In Gait marker configuration. a) Anterior view: manubrium, xyphoid process, bilateral ASIS. b) Posterior view: C7, T10, L4, bilateral PSIS. Bilateral acromion processes are apparent in both views. Other markers can be seen in the photographs that are part of the Plug-In Gait set but not used in determination of thorax and pelvic kinematics. The subject is wearing a harness which was connected to a gantry system to prevent a fall during trials of staircase locomotion, as presented in [18].

provided in [17]. Controls were not asked about falls.

Spherical retroreflective markers were placed in accordance with a modified Helen Hayes (i.e. Plug-In Gait) marker configuration [24]. Specifically, to examine torso kinematics, markers were placed on the posterior aspects of the 7th cervical (C7) and 4th lumbar (L4) vertebrae, acromion processes, manubrium, xiphoid process, 10th thoracic vertebrae, and bilateral anterior and posterior iliac spines (Fig. 1). Details on the definitions of the 3D thoracic and pelvic coordinate systems are provided in [10].

A static calibration trial was collected with the subject standing with feet shoulder-width apart and shoulders abducted to 90°. Subjects practiced walking along the 8 m laboratory runway until walking velocity stabilized. Kinematic data were recorded (120 Hz) with an eight camera movement analysis system (VICON Workstation, VICON Inc., Oxford, UK). Two force plates hidden in the runway (Type 4060, Bertec Corp., Columbus, OH, USA; 1080 Hz) assessed sequential right foot then left foot reaction forces. Right foot heel contact and left foot toe off were determined from force data (1080 Hz). At least five trials were collected of each subject. A trial was considered ‘good’ if the subject contacted the force plates without any visible alteration in gait mechanics.

Kinematic data were filtered using a Woltring filter (MSE = 20). The 3D angles of the thorax and pelvis were calculated with respect to the lab coordinate system using the standard Plug-In Gait conventions [24]. Angular position of the thorax and pelvis were determined at right foot heel contact. These angles include thoracic flexion/extension and pelvic anterior/posterior tilt (i.e. sagittal plane), thoracic lateral lean and pelvic obliquity (i.e. frontal plane), and thoracic and pelvic rotation (i.e. transverse plane). Mediolateral translation C7 and L4 markers and 3D ROMs of the thorax and pelvis during gait were determined between right foot heel contact and left foot toe off. Step width was calculated as the mediolateral distance between the heel markers at right foot heel contact in the lab-referenced frontal plane. Stride length was determined from the displacement of the right toe marker between two consecutive stance phases. Average walking velocity was calculated from the marker on the L4 spinous process during the stride.

We have previously reported that control subjects walked faster than pregnant subjects in either trimester, with no differences between trimesters [25]. An analysis of torso kinematics in advancing pregnancy was presented in [10]; therefore, the current data were pooled across trimesters in order to compare pregnant fallers and non-fallers.

To better understand the mechanisms behind differences in torso kinematics between pregnant fallers and non-fallers, we measured several anthropometric variables of the trunk of the pregnant women. A cloth tape was used to measure waist and hip circumference. The tester stood in front of the subject. Waist circumference was measured at the level of the umbilicus. Hip circumference was measured around the widest part, in accordance with the WHO guidelines [26]. Waist-to-hip ratio was then calculated. To estimate torso length, the distance between each pregnant subject’s acromion process and greater trochanter on her right side was measured using an anthropometer. Additionally, we calculated weight gained during pregnancy by subtracting her self-reported pre-pregnancy weight from her measured weight at each visit.

2.3. Statistical analyses

Statistical analyses were performed with SPSS software (version 24, IBM SPSS Statistics, Armonk, NY, USA). Kinematic variables were organized into three categories for statistical analysis: (1) mediolateral translations of the C7 and L4 markers (2) 3D angular positions of the thorax and pelvis at right heel contact, and (3) 3D angular ROMs of the thorax and pelvis during the stride.

A multivariate analysis of covariance (MANCOVA) was performed on each category of kinematic data ($\alpha = 0.05$). The independent variable was fall group (i.e. pregnant faller, pregnant non-faller, and control). Walking velocity was the covariate in each analysis. If significant differences were found between fall groups, a Tukey post-hoc analysis was performed ($\alpha = 0.05$). An ANOVA examined between group differences in the space-time gait parameters of step width, stride length, and walking velocity ($\alpha = 0.05$). If significant differences were found between fall groups, a Tukey post-hoc analysis was performed ($\alpha = 0.05$).

For the torso anthropometry measures of waist and hip circumferences, waist-to-hip ratio, mass gained in pregnancy, and torso length in the pregnant subjects, we performed a MANOVA between pregnant fallers and non-fallers ($\alpha = 0.05$). As with the kinematic variables, the waist and hip circumferences and the waist-to-hip ratios are averaged across the second and third trimesters.

3. Results

Pregnant fallers exhibited altered thoracic, but not pelvic,

Table 2
3D kinematic variables (mean (standard deviation)) between pregnant fallers, pregnant non-fallers, and controls during the gait cycle. P_F is the p-value for the between pregnant fallers, non-fallers, and controls comparison. P_v is the p-value for velocity, the covariate in the analysis.

		Control	Pregnant Non-Fallers	Pregnant Fallers	p-value
Frontal plane translations					
	C7 (cm)	4.7 (1.8)	6.1 (2.5)	5.8 (2.0)	$P_F = 0.11$ $P_V = 0.01$
	L4 (cm)	4.6 (1.9)	5.8 (2.0)	5.5 (1.6)	$P_F = 0.38$ $P_V = 0.10$
Position at Heel Contact					
Thorax	Sagittal Plane (°)	1.3 (5.2)	−4.9 (5.8)	−4.9 (4.2)	$P_F = 0.71$ $P_V = 0.12$
	Frontal Plane (°)	1.4 (2.4)	1.6 (2.7)	−0.1 (2.3)	$P_F = 0.01$ $P_V = 0.01$
	Transverse Plane (°)	0.9 (3.4)	2.8 (3.7)	0.6 (3.9)	$P_F = 0.01$ $P_V = 0.60$
Pelvis	Sagittal Plane (°)	11.0 (18.3)	15.5 (16.9)	15.5 (6.1)	$P_F = 0.97$ $P_V = 0.73$
	Frontal Plane (°)	4.1 (16.7)	2.9 (7.2)	2.4 (3.6)	$P_F = 0.77$ $P_V = 0.75$
	Transverse Plane (°)	−3.2 (17.0)	−1.7 (14.3)	−4.4 (4.4)	$P_F = 0.15$ $P_V = 0.54$
ROM during the gait cycle					
Thorax	Sagittal Plane (°)	5.8 (2.2)	5.5 (2.8)	5.4 (2.1)	$P_F = 0.87$ $P_V = 0.46$
	Frontal Plane (°)	4.1 (1.9)	4.8 (2.8)	4.2 (2.6)	$P_F = 0.03$ $P_V = 0.01$
	Transverse Plane(°)	7.5 (2.4)	7.8 (2.9)	7.0 (2.4)	$P_F = 0.04$ $P_V = 0.31$
Pelvis	Sagittal Plane (°)	8.2 (3.5)	11.1 (19.1)	9.2 (11.0)	$P_F = 0.22$ $P_V = 0.23$
	Frontal Plane (°)	12.9 (3.8)	13.8 (22.7)	11.7 (3.5)	$P_F = 0.30$ $P_V = 0.87$
	Transverse Plane (°)	14.0 (8.1)	14.8 (18.5)	11.1 (4.2)	$P_F = 0.10$ $P_V = 0.10$
Space-time Gait Parameters					
Step width (cm)		8.7 (3.4)	9.9 (4.0)	8.1 (2.9)	$P_F = 0.001$
Stride length (cm)		149.3 (10.5)	140.3 (10.5)	135.9 (13.9)	$P_F = 0.006$
Walking velocity (m/s)		1.47 (0.16)	1.33 (0.13)	1.28 (0.16)	$P_F = 0.009$

kinematics when compared to pregnant non-fallers and controls. Specifically, pregnant fallers demonstrated less thoracic lateral lean in the frontal plane at heel contact when compared to pregnant non-fallers and controls ($P = 0.01$). Pregnant fallers also demonstrated less thoracic rotational ROM ($P = 0.036$) during the gait cycle when compared to pregnant non-fallers, although neither group was different from the controls (Table 2).

Pregnant non-fallers had greater step width during gait compared to pregnant fallers and controls ($P = 0.001$), who did not differ from each other. Controls had greater stride length and walking velocity than did the pregnant non-fallers, who in turn demonstrated greater values than the pregnant fallers ($P = 0.006$ and 0.009, respectively) (Table 2).

Pregnant non-fallers had greater thoracic rotation at heel strike than pregnant fallers and controls ($P = 0.001$). Additionally, compared to pregnant fallers and controls, pregnant non-fallers exhibited greater frontal plane ROM of the thorax throughout the stride ($P = 0.03$). No other differences were noted between pregnant fallers, non-fallers, and controls (Table 2). No anthropometric differences were noted between pregnant fallers and non-fallers (Table 3).

4. Discussion

The purpose of this study was to examine thoracic and pelvic kinematics during gait in pregnant fallers, pregnant non-fallers, and a BMI and parity-matched non-pregnant control group. We hypothesized that frontal plane mediolateral translation of the trunk and angular motion of the thorax and pelvis would be greatest in pregnant fallers.

Table 3
Anthropometric measures (mean (standard deviation)) between pregnant fallers and non-fallers, collapsed across trimesters.

	Pregnant Non-Fallers	Pregnant Fallers	p-value
Waist Circumference (cm)	98.4 (13.5)	99.6 (10.7)	P = 0.69
Hip Circumference (cm)	108.2 (9.1)	109.8 (8.1)	P = 0.41
Waist to Hip Ratio	0.91 (0.10)	0.91 (0.06)	P = 0.72
Mass gain in pregnancy (kg)	10.3 (6.8)	10.4 (6.1)	P = 0.86
Acromion to Hip length (cm)	52.7 (4.6)	53.2 (6.0)	P = 0.15

Although we found significant differences between pregnant fallers and non-fallers, our results do not support these hypotheses. Pregnant fallers demonstrated smaller frontal and transverse plane angles at heel strike and ROMs throughout the stride as well as a smaller step width. In each of these variables, the magnitude was greater in pregnant non-fallers, implying that pregnant non-fallers demonstrate greater thoracic movement than pregnant fallers. The larger amount of torso movement may also be indicative of less torso rigidity or greater adaptability that would allow pregnant non-fallers to be more likely to successfully overcome a trip, slip, or mediolateral fall. An alternate theory for why the pregnant non-fallers demonstrated greater transverse plane thoracic motion could be that it is due to the increased stride length compared to the pregnant fallers. Sawa et al. [15] reported that women in their third trimester have a decreased anteroposterior control of trunk movement. However, as they did not compare fallers vs non-fallers, their results have limited applicability to the current study. Also, the greater step width of the pregnant non-fallers indicates a larger base of support, and thus increased stability. Increased step width was also noted by Foti et al. [12]. Pregnant non-fallers may have used this greater step width to accommodate their greater thoracic ROM in the frontal plane. Alternatively, the greater thoracic frontal plane thoracic ROM could simply be due to the wider step width, rather than the converse of this.

There were not anthropometric differences of the torso between pregnant fallers and non-fallers. Our hypothesis that anthropometrics may explain kinematic differences seen between the groups was based upon research showing obese individuals have a increased fall-risk [22]. However, this hypothesis was not supported, suggesting that differences were rather due to postural stability or locomotor changes rather than torso anthropometry. We did not have pre-pregnancy anthropometric data on these women, so we cannot ascertain how much waist and hip circumference had changed during pregnancy. Perhaps it is not the absolute value of the circumference, but rather the change during pregnancy that affected fall risk more. However, mass gain during pregnancy was not different between the groups.

Differences in other biomechanical parameters have been noted between the fallers and non-fallers in our cohort of pregnant women. Specifically, these pregnant fallers have demonstrated less center of pressure movement in reaction to a translational perturbation to quiet stance [17], as well as altered ground reaction forces during staircase ascent and descent [18]. If the falls experienced by pregnant women were caused by random environmental factors, then we would not have seen differences between fallers and non-fallers in our laboratory assessments; however, the fact that biomechanical differences exist between groups indicates that the falls were not due to random occurrences, but rather they were due, in part, to intrinsic factors within these women. There is no evidence that anthropometric factors contribute to these intrinsic differences between pregnant fallers and non-fallers, as we did not find differences between pregnant fallers and non-fallers in any of the anthropometric variables assessed. Rather, we propose that exercise participation may be an important contributing factor in the prevention of falls.

In a previous publication on this same cohort, we surveyed the 29 pregnant women about their exercise habits during this pregnancy

[17]. The data revealed that sedentary pregnant women were significantly more likely to fall than those who participated in regular exercise ($P = 0.005$) [17]. Therefore, we suggest that exercise during pregnancy enables a woman to better adapt to her rapidly changing body. This idea is supported by the research of Forczek and colleagues [11] which determined that pregnant women who exercise demonstrate beneficial adaptations to lower limb kinematics during gait. Specifically related to this study, they noted a positive correlation between physical activity and walking velocity and stride length and a negative correlation between physical activity and step width [11]. In our current study, the pregnant non-fallers adapted by increasing step width, and thus base of support, compared to pregnant fallers, who did not increase step width in pregnancy. The pregnant non-fallers also had more thoracic frontal plane lean and transverse plane rotation at heel contact as well as greater ROM of these parameters during the gait cycle compared to pregnant fallers. Greater torso movement may have allowed the center of mass to move closer toward the base of support during single stance phase. Also, a less rigid, more flexible and adaptive torso may be better able to react to a fall perturbation, such as a trip or slip. Exercise may enable a woman to learn how her body moves as her pregnancy advances, so that she may develop strategies to stabilize her body and recover from a perturbation during gait. These conclusions are supported by the results of Krkeljas [14], who asserted that more pregnant women should be given exercise programs targeting core strength and pelvic stability in order to prevent falls. Our previous study on this same cohort of pregnant women revealed that pregnant fallers had a smaller response of the center of pressure to a four-aft perturbation to quiet stance [17]. This is also suggestive of a stiffer, more rigid, body [17].

There are a number of limitations to this study. We did not assess static ROM of the thorax or pelvis of the pregnant women, so we do not know if pregnant non-fallers have a greater flexibility of the torso than do pregnant fallers. Because our pregnant fallers reported falling in each of the three trimesters, and because some fell in multiple trimesters, we are not able to determine if torso biomechanics are altered once a fall has occurred. We did not assess kinesthetic awareness or proprioception, so we do not know if these parameters are better in the pregnant non-fallers. We did not assess pre-pregnancy waist and hip circumference so we do not know if the change in these variables affected movement during pregnancy. However, the absolute circumference did not differ between the fallers and non-fallers.

Future studies should examine if the coordination pattern between the thorax and pelvis during gait differs between pregnant fallers and non-fallers. The smaller movement of the thorax in pregnant fallers may point toward altered coordination of movement that may indicate greater torso rigidity in women who fall while pregnant. There is also a need for further investigation of the efficacy of exercise in fall prevention in pregnant women.

5. Conclusions

Pregnant fallers and non-fallers differ in how their gait adapts to the anatomical and physiological changes associated with pregnancy. Pregnant fallers display less frontal and transverse plane movement of the thorax at heel strike and over the course of the gait cycle. Pregnant fallers also do not exhibit the increased step width seen in the pregnant non-fallers. Anthropometric measures of the torso do not differ between groups. Exercise participation may allow pregnant women to better adapt to their rapidly changing physiques and be more adept at recovering their balance should a trip or slip occur.

Funding

This work was supported by the National Institute of Occupational Safety and Health [NIOSH K01 OH8548].

Declaration of Competing Interest

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

Acknowledgements

We would like to thank Kristen Berger and Leah Enders for their many hours of work on this project. We also owe a debt of gratitude 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.

References

[1] K. Dunning, G. Lemasters, A. Bhattacharya, A major public health issue: the high incidence of falls during pregnancy, Matern. Child Health J. 14 (5) (2010) 720–725 http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=19672702.

[2] J. Fildes, L. Reed, N. Jones, M. Martin, J. Barrett, Trauma: the leading cause of maternal death, J. Trauma 32 (5) (1992) 643–645 http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=1588654.

[3] H.B. Weiss, T.J. Songer, A. Fabio, Fetal deaths related to maternal injury, JAMA 286 (15) (2001) 1863–1868 http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=11597288.

[4] W.L. Gilleard, Trunk motion and gait characteristics of pregnant women when walking: report of a longitudinal study with a control group, BMC Pregnancy Childbirth 13 (2013) 71–78 http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=23514204.

[5] C. Schauberger, B. Rooney, L. Goldsmith, D. Shenton, P. Silva, A. Schaper, Peripheral joint laxity increases in pregnancy but does not correlate with serum relaxin levels, Am. J. Obstet. Gynecol. 174 (1996) 667–671.

[6] G.A. Dumas, J.G. Reid, L.A. Wolfe, M.P. Griffin, M.J. McGrath, Exercise, posture, and back pain during pregnancy, Clin. Biomech. Bristol Avon (Bristol, Avon) 10 (2) (1995) 98–103 http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=11415538.

[7] H. Yoo, D. Shin, C. Song, Changes in the spinal curvature, degree of pain, balance ability, and gait ability according to pregnancy period in pregnant and nonpregnant women, J. Phys. Ther. Sci. 27 (2015) 279–284.

[8] W.L. Gilleard, J.M.M. Brown, Structure and function of the abdominal muscles in primigravid subjects during pregnancy and the immediate postbirth period, Phys. Ther. 76 (7) (1996) 750–762 < Go to ISI > ://A1996UW60100010.

[9] W.H. Wu, O.G. Meijer, C.J.C. Lamoth, K. Uegaki, J.H. van Dieen, P.I.J.M. Wuisman, et al., Gait coordination in pregnancy: transverse pelvic and thoracic rotations and their relative phase, Clin. Biomech. 19 (5) (2004) 480–488 < Go to ISI > ://000222157700006.

[10] J.L. McCrory, A.J. Chambers, A. Daftary, M.S. Redfern, The pregnant "Waddle": an evaluation of torso kinematics in pregnancy, J. Biomech. 47 (2014) 2964–2968.

[11] W. Forczek, Y. Ivanenko, M. Curylo, B. Fraczek, A. Maslon, M. Salamage, et al., Progressive changes in walking kinematics throughout pregnancy - A follow up study, Gait Posture 68 (2019) 518–524.

[12] T. Foti, J.R. Davids, A. Bagley, A biomechanical analysis of gait during pregnancy, Journal of Bone and Joint Surgery-American Volume 82A (5) (2000) 625–632 < Go to ISI > ://000087009400003.

[13] A. ElDeeb, H. Hamada, A. Abdel-Aziem, A. Youssef, The relationship between trunk and pelvis kinematics during pregnancy trimesters, Acta Bioeng. Biomech. 18 (4) (2016) 79–85.

[14] Z. Krkeljas, Changes in gait and posture as factors of dynamic stability during walking, Hum. Mov. Sci. 58 (2018) 315–320.

[15] R. Sawa, T. Doi, T. Asai, K. Watanabe, T. Taniguchi, Differences in trunk control between early and late pregnancy during gait, Gait Posture 42 (2015) 455–459.

[16] W.L. Gilleard, J. Crosbie, R. Smith, Static trunk posture in sitting and standing during pregnancy and early postpartum, Arch. Phys. Med. Rehabil. 83 (12) (2002) 1739–1744 < Go to ISI > ://000179677700009.

[17] J.L. McCrory, A.J. Chambers, A. Daftary, M.S. Redfern, Dynamic postural stability in pregnant fallers and non-fallers, BJOG 117 (8) (2010) 954–962 http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=20536431.

[18] J.L. McCrory, A.J. Chambers, A. Daftary, M.S. Redfern, Ground reaction forces during stair locomotion in pregnant fallers and non-fallers, Clin. Biomech. Bristol Avon (Bristol, Avon) 29 (2) (2013) 143–148 http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=24359627.

[19] N. Mortaza, N. Abu Osman, N. Mehdikhani, Are the spatio-temporal parameters of gait capable of distinguishing a faller from a non-fallers elderly? European Journal of Physical and Rehabilitations Medicine 50 (6) (2014) 677–691.

[20] M.E. Taylor, K. Delbaere, A.S. Mikolaizak, S.R. Lord, J.C.T. Close, Gait parameter risk factors for falls under simple and dual task conditions in cognitively impaired

older people, Gait Posture 37 (1) (2013) 126–130 < Go to ISI > :// 000313311900022.

[21] L.S. Chou, K.R. Kaufman, M.E. Hahn, R.H. Brey, Medio-lateral motion of the center of mass during obstacle crossing distinguishes elderly individuals with imbalance, Gait Posture 18 (3) (2003) 125–133 http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=14667945.

[22] R.J. Mitchell, S.R. Lord, L.A. Harvey, J.C. Close, Associations between obesity and overweight and fall risk, health status and quality of life in older people, Aust. N. Z. J. Public Health 38 (1) (2014) 13–18 http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=24494939.

[23] C.H. Lin, K.C. Liao, S.J. Pu, Y.C. Chen, M.S. Liu, Associated factors for falls among the community-dwelling older people assessed by annual geriatric health examinations, PLoS One 6 (4) (2011) e18976 http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=21526155.

[24] VICON, Plug-in-Gait Modelling Instructions, VICON Manual, VICON 612 Motion Systems, Oxford Metrics, LTD, Oxford, UK, 2002.

[25] J.L. McCrory, A.J. Chambers, A. Daftary, M.S. Redfern, Ground reaction forces during gait in pregnant fallers and non-fallers, Gait Posture 34 (2011) 524–528.

[26] W.H. Organization, Waist Circumference and Waist–Hip Ratio: Report of a WHO Expert Consultation World Health Organization, Geneva, Switzerland, (2011), pp. 5–7.