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Ground reaction forces during gait in pregnant fallers and non-fallers

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ABSTRACT

Pregnant women are at a high risk of experiencing a fall. To our knowledge, ground reaction forces (GRFs) in pregnant fallers and non-fallers have not been reported.

Purpose: The purpose of this study was to examine the effects of pregnancy and fall history on GRFs during walking.

Methods: Forty one pregnant subjects in the mid 2nd and 3rd trimesters (pregnant fallers: $n = 15$, pregnant non-fallers: $n = 14$), and 40 control women walked at a freely chosen walking speed along an 8 m walkway. A force plate, hidden in the walkway, was used to collect GRFs (1080 Hz). Kinematic data (120 Hz) were collected from a marker placed on the lumbar spine to estimate walking velocity. GRF variables included mediolateral Center of Pressure (COP) excursion, and GRFs normalized to body mass. A two factor ANOVA (trimester x fall group) was used to compare subject demographics, and walking velocity ($\alpha = 0.05$). A two factor ANCOVA (trimester $\times$ fall group, covariate: velocity) was performed to examine other GRF variables (Bonferroni corrected $\alpha = 0.006$) and the mediolateral COP excursion ($\alpha = 0.05$).

Results: Walking velocity was greater in the control group ($p < 0.05$). No differences were seen in the GRFs or COP movement between trimesters or between pregnant fallers and non-fallers.

Conclusions: When walking velocity was considered in the statistical model, ground reaction forces are essentially unchanged by pregnancy.

1. Introduction

Pregnant women are at a high risk of falling compared to non-pregnant women. Approximately 28% of pregnant women fall while pregnant, making falls a leading cause of emergency department hospital admissions related to trauma in pregnancy [1]. Most falls occur during the second trimester [1,2]. Although physiological changes are greatest in the third trimester, most women curtail activity in the last trimester and are not in as many fall-risk situations [1]. Pregnant women who fall may sustain bone fractures, joint sprains, muscle strains, head injury, rupture of internal organs, placental separation, and occasionally maternal or fetal death [3–6].

Numerous anatomical, physiological, and hormonal alterations during pregnancy may be related to the increased risk of falling. Pregnant women experience increased spinal lordosis [7], increased ligamentous laxity [8], substantial weight gain [7–9], decreased abdominal muscle strength [10], and swelling of the arms and legs [11]. Additionally, decreased neuromuscular control and coordination [12,13], altered biomechanics [14–16], an anterior shift in the location of the center of mass [17], and changes in mechanical loading and joint kinetics have been noted in pregnant women [18,19].

Several studies have investigated the gait biomechanics of pregnant women. Foti et al. reported increased lower extremity joint moments and powers during gait but little change in joint kinematics in pregnant women in the latter half of their third trimesters [14]. A greater step width in late-stage pregnancy when compared to post-partum has been reported [14,18]. Lymbery and Gilleard found no significant differences in ground reaction forces (GRFs) or walking speed in women in their third trimesters compared to post-partum [18]. However, the mediolateral position of the center of pressure (COP) during stance was shifted laterally [18]. Enders et al. reported greater side-to-side motion in pregnant women, as evidenced by movement of the C7 spinal segment [17].

Although the risk of experiencing a fall during pregnancy is elevated [1,20], few studies have reported biomechanical differences in pregnant women who have fallen compared to those who

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have not. In the same group of women included in the present study, we noted a decreased response of the COP to a translation perturbation to quiet stance in pregnant fallers [21]. To our knowledge, no studies have been performed to investigate GRFs between the trimesters of pregnancy. Also, no referenced studies on gait biomechanics in pregnant fallers compared to non-fallers were found.

The purpose of this study was to compare GRFs, normalized by body mass, during gait in the second and third trimesters of pregnancy in pregnant women who have fallen during their pregnancy, pregnant women who have not fallen, and non-pregnant women. When considering the effect of pregnancy on GRFs, we hypothesized that the medial and lateral GRF impulses and mediolateral COP excursion would be larger in the pregnant women, particularly during their third trimester because of the larger frontal plane movement associated with pregnancy. When considering whether or not the subject fell during pregnancy, we hypothesized that pregnant women who have fallen would have larger medial and lateral GRF impulses and greater mediolateral COP excursion compared to those who have not fallen.

2. Methods

2.1. Subjects

Eighty one women (41 pregnant, 40 non-pregnant controls) between the ages of 18 and 45 years participated in this study. Subject demographics are shown in Table 1. Pregnant participants were recruited through the UPMC Womancare Research Registry in the beginning of their second trimester. Non-pregnant controls were recruited via advertisements placed around the university. Control and pregnant participants were matched to within 2 kg/m^2 body mass index (BMI), based on the pregnant woman's self-reported pre-pregnancy mass.

Potential pregnant participants were excluded from the study if they were beyond their 20th week of pregnancy, were carrying multiple fetuses, or if they had a history of any of the following: delivery of an older child prior to 36 weeks of gestation, toxemia, gestational hypertension, pre-eclampsia, gestational diabetes, or if they were considered by their obstetrician to have a high-risk pregnancy. Potential control or pregnant participants were excluded if they were not between the ages of 18 and 45 years, had a lower extremity fracture within the last five years, ankle or knee sprain within the last year, current back or knee pain, a history of type I or type II diabetes or any other condition which could affect their sensation, or a history of ligament rupture at the ankle or knee. Subjects were also excluded if they were a current smoker, if they currently took any medication which would affect their gait or balance mechanics, or if they typically consumed more than one alcoholic drink per day.

Pregnant subjects participated in two data collection sessions. The first session occurred in the middle of their second trimester.

Table 1
Subject demographics (mean ± standard deviation).

	Control group (n = 40)	Pregnant group (n = 29)	
Age (years)	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)*	64.7 ± 8.8	73.9 ± 9.9	81.3 ± 11.1

* 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 groups ($p > 0.05$).

The average gestational age during the first data collection session was 20.9 ± 1.2 weeks. The second session occurred during the middle their third trimester at 35.8 ± 1.5 weeks.

Twelve pregnant subjects did not participate in their third trimester testing session. The reasons were as follows: delivery of the baby prior to 35 weeks (n = 4), decision to withdraw from study (n = 4), pre-eclampsia or other complications (n = 2), injuries sustained from a fall required the subject to be placed on bed rest (n = 1), and relocation away from the area (n = 1). The data from these women are not included in the statistical analysis.

We did not match subjects in the pregnant and control groups based on the number of previous pregnancies. In the pregnant group, 27 women were primigravid, five stated it was their second pregnancy, and nine of the women said it was their third pregnancy. Thirty-three of the control women were nulligravid. Six controls reported that they were pregnant one time and one reported that she had been pregnant twice.

Control subjects participated in a single study visit. Because estrogen and progesterone are believed to influence movement patterns, flexibility, and dexterity [22,23], data of the control group were collected in the week following menses. During this week, concentrations of both estrogen and progesterone are at a low point in the menstrual cycle [24]. Additionally, by collecting these data immediately following menses, we were certain that these women were not pregnant.

2.2. Procedures

Subjects reported to the Human Movement and Balance Laboratory on the campus of the University of Pittsburgh for testing. Experimental procedures were explained to the subject, who was encouraged to ask questions. Written informed consent was then obtained.

Pregnant subjects completed a survey about their history of falls during this pregnancy, as well as an assessment of their exposure to common risk factors for falling. More details and the results of the fall survey can be found in [21]. Of the 29 pregnant subjects who completed the study, 15 reported falling at least once [21]. A fall was defined as losing their balance such that another part of their body other than a foot touched the ground. A total of 24 falls were reported [21]. If a subject reported a fall in this pregnancy, she was categorized as a "pregnant faller". Those who did not fall were categorized as "pregnant non-fallers".

Each subject's height and mass were obtained using a standard medical balance-beam scale and stadiometer. Subjects wore comfortable clothing and athletic shoes. A spherical retroreflective marker was placed on the L3L4 spinal segment for use in determining walking velocity.

Each participant was given practice walking at her freely chosen walking speed on the 8 m vinyl tile laboratory walkway. A Bertec force plate (Type 4060, Bertec Corp, Columbus, OH, 1080 Hz) was imbedded in the walkway and camouflaged with floor tiles to minimize subject awareness of its presence. The subject's starting position was adjusted until her right foot contacted the force plate without any visible alteration in gait mechanics. Five trials were collected. Movement of the marker on the L3L4 spinal segment was captured with a VICON Workstation system (VICON, Inc., Denver, CO, 120 Hz); from this, walking velocity was calculated as the average velocity of the marker during the entire time that it was visible on the VICON system.

The GRF data were processed using a custom-written m-file in Matlab (Version R2008a. Mathworks, Inc., Natick, MA). Data were filtered with a fourth order low-pass, phaseless Butterworth filter with a cutoff frequency of 50 Hz. Heel contact was determined when the vertical GRF exceeded 5% of body weight. Toe-off occurred when the vertical GRF went below 5% of body weight.

Mediolateral excursion of the COP during the stance phase was calculated as the difference between the maximum medial and lateral positions of the COP. The following variables were determined from the anterioposterior shear forces: braking peak, time to braking peak, propulsive peak, time to propulsive peak, and braking and propulsive impulses. Medial and lateral impulses were determined from the mediolateral shear forces. Passive peak, time to passive peak, active peak, time to active peak, minimum between peaks, time to minimum between peaks, loading rate, and impulse were calculated from the vertical GRFs. Loading rate was calculated as the passive peak divided by the time to the passive peak. All forces were normalized to body weight.

2.3. Statistical analysis

A two-factor ANOVA (trimester, fall group) was performed on each of the following variables: age, height, mass, and walking velocity ($\alpha = 0.05$). Trimester had three levels (control, second trimester, third trimester), and fall group had three levels (control, pregnant faller, pregnant non-faller). Subsequently, a two-factor (trimester, fall group) analysis of covariance (ANCOVA) was performed on each of the GRF variables and the mediolateral excursion of the COP. Because walking velocity affects GRFs [25], it was included as a covariate in our statistical analyses.

Bonferroni corrections were applied to an overall α level of 0.05 such that the corrected α-value for the eight shear force variables (braking peak, time to braking peak, propulsive peak, time to propulsive peak, braking impulse, propulsive impulse, medial impulse and lateral impulse) was 0.006. The Bonferroni-corrected α-value for the eight vertical GRF variables (passive peak, time to passive peak, loading rate, minimum between peaks, time to minimum between peaks, active peak, time to active peak, and vertical impulse) was 0.006. The alpha value for the COP comparison was 0.05.

For each of the above comparisons, Tukey post hoc tests were performed when appropriate to determine where the significant differences were between the fall groups (controls, pregnant fallers, and pregnant non-fallers) as well as between the trimesters ($\alpha = 0.05$).

3. Results

Walking velocity was significantly different among the controls and pregnant subjects in their second and third trimesters ($p = 0.048$). The Tukey post hoc test revealed significant differences between the controls, pregnant subjects in their second trimester, and pregnant subjects in their third trimester (each $p < 0.05$). Control subjects walked the fastest (1.47 ± 0.16 m/s). Velocity was less in pregnant women in their second trimester (1.34 ± 0.15 m/s). The pregnant women in their third trimester had the slowest walking velocity (1.29 ± 0.13 m/s). Additionally, the pregnant women who fell walked more slowly (1.28 ± 0.16 m/s) than the pregnant women who had not fallen (1.33 ± 0.13 m/s), which was also significantly slower ($p = 0.008$) than the control subjects. The Tukey post hoc test revealed significant differences between the controls, pregnant fallers, and pregnant non-fallers (each $p < 0.05$). The trimester $\times$ fall fall group interaction was not significant ($p = 0.080$).

When walking velocity was considered, no differences were noted between trimesters or between fall groups in the shear force variables (Table 2) or in the vertical force variables (Table 3). The trimester $\times$ fall group interactions were not significant. However, the effect of walking velocity, which was a covariate in the model,

Table 2
Shear force variables. The data shown are the means (standard deviations). The Bonferroni corrected p-value was set to 0.006. p_T is the p-value for the independent factor of "trimester". p_F is the p-value for the independent factor of "fall group". p_{TF} is the p-value for the "trimester" $\times$ "fall group" interaction term. p_v is the p-value for the covariate velocity.

	Control	Second trimester		Third trimester		p values
		Non-faller	Faller	Non-faller	Faller	
Braking Pk (BW)	−0.236 (0.046)	−0.206 (0.035)	−0.205 (0.027)	−0.195 (0.036)	−0.208 (0.026)	$p_T = 0.962$ $p_F = 0.011$ $p_{TF} = 0.671$ $p_V = 0.001$
Time to braking Pk (s)	0.096 (0.015)	0.099 (0.016)	0.105 (0.015)	0.104 (0.017)	0.107 (0.017)	$p_T = 0.389$ $p_F = 0.212$ $p_{TF} = 0.800$ $p_V = 0.001$
Propulsive Pk (BW)	0.256 (0.046)	0.223 (0.028)	0.214 (0.027)	0.215 (0.027)	0.224 (0.032)	$p_T = 0.544$ $p_F = 0.011$ $p_{TF} = 0.917$ $p_V = 0.001$
Time to propulsive Pk (s)	0.528 (0.042)	0.549 (0.043)	0.564 (0.042)	0.572 (0.049)	0.570 (0.043)	$p_T = 0.175$ $p_F = 0.099$ $p_{TF} = 0.857$ $p_V = 0.001$
Braking impulse (BW s)	−0.032 (0.005)	−0.031 (0.005)	−0.032 (0.004)	−0.031 (0.006)	−0.033 (0.004)	$p_T = 0.337$ $p_F = 0.009$ $p_{TF} = 0.306$ $p_V = 0.039$
Propulsive impulse (BW s)	0.035 (0.006)	0.032 (0.005)	0.033 (0.004)	0.033 (0.006)	0.035 (0.004)	$p_T = 0.131$ $p_F = 0.031$ $p_{TF} = 0.548$ $p_V = 0.489$
Medial impulse (BW s)	−0.020 (0.007)	−0.021 (0.007)	−0.023 (0.006)	−0.024 (0.009)	−0.024 (0.005)	$p_T = 0.074$ $p_F = 0.967$ $p_{TF} = 0.433$ $p_V = 0.001$
Lateral impulse (BW s)	0.0022 (0.0011)	0.0021 (0.0010)	0.0016 (0.0009)	0.0017 (0.0009)	0.0019 (0.0011)	$p_T = 0.767$ $p_F = 0.956$ $p_{TF} = 0.050$ $p_V = 0.001$

Table 3
Vertical force variables. The data shown are the means (standard deviations). The Bonferroni corrected p-value was set to 0.006. p_T is the p-value for the independent factor of "trimester". p_F is the p-value for the independent factor of "fall group". p_{TF} is the p-value for the "trimester" × "fall group" interaction term. p_v is the p-value for the covariate velocity.

	Control	Second trimester		Third trimester		p values
		Non-faller	Faller	Non-faller	Faller	
Passive Pk (BW)	1.17 (0.14)	1.12 (0.07)	1.10 (0.06)	1.11 (0.06)	1.11 (0.05)	$p_T = 0.163$ $p_F = 0.393$ $p_{TF} = 0.662$ $p_V = 0.001$
Time to passive Pk (s)	0.13 (0.03)	0.15 (0.02)	0.15 (0.03)	0.16 (0.02)	0.16 (0.03)	$p_T = 0.230$ $p_F = 0.730$ $p_{TF} = 0.924$ $p_V = 0.001$
Loading rate (BW s)	9.41 (2.64)	8.01 (1.85)	7.41 (1.54)	7.29 (1.16)	7.24 (1.32)	$p_T = 0.549$ $p_F = 0.727$ $p_{TF} = 0.999$ $p_V = 0.001$
Min bet peaks (BW)	0.64 (0.11)	0.70 (0.06)	0.74 (0.06)	0.74 (0.05)	0.73 (0.05)	$p_T = 0.683$ $p_F = 0.831$ $p_{TF} = 0.395$ $p_V = 0.001$
Time to min bet peaks (s)	0.30 (0.03)	0.31 (0.03)	0.31 (0.03)	0.32 (0.03)	0.33 (0.03)	$p_T = 0.039$ $p_F = 0.169$ $p_{TF} = 0.130$ $p_V = 0.001$
Active Pk (BW)	1.15 (0.12)	1.09 (0.07)	1.10 (0.60)	1.05 (0.47)	1.09 (0.58)	$p_T = 0.273$ $p_F = 0.020$ $p_{TF} = 0.545$ $p_V = 0.001$
Time to active Pk (s)	0.48 (0.04)	0.49 (0.04)	0.51 (0.04)	0.51 (0.04)	0.51 (0.04)	$p_T = 0.279$ $p_F = 0.924$ $p_{TF} = 0.620$ $p_V = 0.001$
Vertical impulse (BW s)	0.501 (0.055)	0.515 (0.041)	0.529 (0.030)	0.530 (0.043)	0.536 (0.031)	$p_T = 0.382$ $p_F = 0.878$ $p_{TF} = 0.755$ $p_V = 0.001$

was significant ($p < 0.006$) in every statistical comparison except for the braking and propulsive impulse.

The excursion of the COP in the mediolateral direction during the stance phase of gait was also calculated. Walking velocity was a significant covariate in the statistical model ($p = 0.023$). There were no significant differences between trimesters ($p = 0.21$) or fall groups ($p = 0.44$). The trimester x fall group interaction was not significant ($p = 0.26$). The women in the control group had a mediolateral excursion of the COP of 28.6 ± 11.6 mm, while pregnant women in their second and third trimesters demonstrated excursions of 29.3 ± 11.2 and 31.9 ± 11.7 mm, respectively. The mediolateral COP excursions of the pregnant non-fallers and fallers were 29.9 ± 12.1 and 30.9 ± 10.6 mm, respectively.

4. Discussion

The purpose of our study was to examine the effects of advancing pregnancy and fall history on GRFs during gait. We hypothesized that the mediolateral GRF impulses and the mediolateral COP excursion would be larger in the pregnant women, particularly during their third trimester and that pregnant fallers would have larger mediolateral GRF impulses and greater mediolateral COP excursion than pregnant non-fallers and non-pregnant controls.

Several researchers have reported frontal plane kinematic differences in pregnant vs non-pregnant women. Enders and colleagues reported greater mediolateral movement of the cervical spine in this same sample of pregnant and control women during their third trimesters [17]. Additionally, Foti et al. reported a wider stance width and greater hip adduction during loading during pregnancy [14]. Similarly, alterations in frontal plane kinetics during pregnancy have been noted. Lymbery and Gilleard reported that women in their third trimester exhibited a lateral shift of the COP during gait, although the mediolateral excursion of the COP was not reported [18]. Foti et al. stated that pregnancy was associated with a greater stance phase hip abduction moment [14].

Walking velocity was a significant covariate in each of our statistical analyses. Increased walking speed is accompanied by shortened contact times and larger peak forces [25]. Our pregnant group demonstrated a slower walking velocity than the control group. This same pattern holds true when comparing the pregnant fallers, non-fallers, and controls. This slower walking velocity may be a compensatory mechanism to keep ground reaction forces unchanged despite differences in body mass.

No differences in the selected GRF variables were noted between the pregnant women and the controls, nor between the pregnant fallers and non-fallers. Our results are supported by Lymbery and Gilleard [18], who did not find a difference in walking velocity between the third trimester and post-partum collection sessions [18]. While we noted differences in walking velocities between trimesters and between the pregnant women and the control group, we accounted for velocity in the statistical analysis.

To our knowledge, no other studies have compared mediolateral COP excursion during pregnancy, particularly in pregnant fallers and non-fallers. When walking velocity was included in the statistical model, we did not find differences between either the trimesters or the fall groups. The pregnant fallers in their third trimester exhibited a 34.1 mm mediolateral excursion of the COP, compared to pregnant non-fallers (29.9 mm) and controls (28.6 mm). Because walking velocity was a significant covariate, these non-significant differences in COP excursion between the pregnant fallers, non-fallers, and controls are likely attributable to the slower walking velocity of the pregnant fallers. However, Foti et al. [14] reported a wider step-width during pregnancy. This mediolateral COP excursion may also be a result of a wider base of support, which could be an attempt to increase frontal plane stability.

GRFs have been examined in other populations at a high risk of falling. Barela and Duarte noted decreased vertical peak GRFs in elderly individuals [26]. However, these data were not normalized to walking velocity. Egerton et al. reported greater frontal plane COP movement during a step up task in balance-impaired elderly compared to healthy age-matched controls [27]. Additionally, individuals with a high and low levels of spasticity due to Multiple Sclerosis demonstrated greater mediolateral COP movement during a standing task, but no differences in anterioposterior sway compared to controls [28].

Future studies are planned to investigate the kinematics and joint kinetics of pregnant women in the second and third trimesters. We also plan to determine if differences in joint kinematics and kinetics exist between pregnant fallers and non-fallers. This information will allow us to better understand a possible altered center of mass control mechanism that may occur during pregnancy.

5. Conclusion

Pregnant women in their latter trimesters as well as pregnant women who have experienced a fall did not demonstrate altered GRF patterns or mediolateral COP excursion during stance compared to a control group of non-pregnant women.

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Conflict of interest statement

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

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