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List of Terms and Abbreviations

Anthropometry: Study of the dimensions and weights of body segments [1].

Base of Support (BOS): The area encompassed by both feet on the ground.

Center of Mass (COM)- The point at which the body's mass is evenly distributed.

Center of Pressure (COP): Location of the average force under the subject's feet.

C7:7th cervical vertebra

Initial Sway: The maximum fore-aft COP movement immediately following translation.

Joint Moment: The net effect of muscle activity at a joint can be calculated in terms of net muscle moments [2]. Also called Joint Torque.

Kinematics: Study of the description of motion including considerations of space and time [1]. Joint angles, velocity, and range of motion are considered kinematic measures.

Kinetics: Study of the actions of forces [1]. Ground reaction forces, joint forces, and joint moments are considered kinetic measures.

Reaction time: The time from translation onset until the COP moved independently of the force plates.

Range of Motion (ROM): The total amount of movement during a stride.

Stride: A complete gate cycle from when one foot strikes the ground until the same foot strikes the ground.

Sway Velocity: The initial sway divided by the time from the onset of COP movement to the time of the initial sway.

Total Sway: Total sway was defined as the total fore-aft movement of the COP.

Abstract
Approximately 27% of pregnant women report a fall during their pregnancies [3]. Pregnant women undergo numerous anatomical, physiological, and hormonal changes that may be related to an increased risk of falling [4]. Factors that contribute to this increase risk of falling are unknown, as little research has been performed to study gait and postural stability biomechanics during pregnancy. The **purpose** of this research study was to investigate the changes to dynamic stability of pregnant women during gait, stair ascent and descent, and perturbed stance. We hypothesized the following would occur with advancing pregnancy: the anterior position of the center of mass with respect to the base of support, the trial to trial intra-subject variability on selected gait parameters, the required joint torques, and the reaction time and response amplitude in response to a mild postural perturbation would all increase. **Methods:** Forty one pregnant women (age: 29.5±4.9 yrs, hgt: 1.7±0.7 m, 2nd trimester mass: 74.7±12.1 kg, 3rd trimester mass: 81.6±11.0 kg) and 40 non-pregnant controls (age: 26.5±6.4 yrs, hgt: 1.7±0.6 m, mass: 66.0±8.9 kg) participated. Data were collected on the pregnant women in the middle of their 2nd and 3rd trimesters and on the control women in the week following menses. After obtaining consent, pregnant subjects were surveyed about previous pregnancies, current exercise participation, current employment, as well as history of falls while pregnant. Thirty-two anthropometric measures were recorded to determine the location of the center of mass of the torso. Biomechanical movement data were collected of the subject during gait, as well as during stair ascent and descent. Dynamic postural stability data were collected using an Equitest system (NeuroCom Inc., Clackamas, OR). For each of the gait variables, a two-factor ANOVA was performed with group (control or pregnant) and trimester as the independent variables ($\alpha=0.05$). For the balance data, a mixed-model ANOVA was performed on each variable ($\alpha=0.05$). Additionally, 60% of the pregnant subjects reported falling. Therefore, subsequent two-factor ANOVAs were performed on the gait and balance data with group (control, pregnant faller, pregnant non-faller), and trimester as the independent variables ($\alpha=0.05$). **Results**: Pregnant women did not demonstrate greater mediolateral motion at either the COM or at C7 when compared to the control group. The BoS was wider during pregnancy, as expected. The non-pregnant control group exhibited greater knee flexion moments than the pregnant group. The amount of variability of these measures was not increased during pregnancy. For the balance data, reaction time was not different between the pregnant women and controls, regardless of trimester. Initial sway, total sway, and sway velocity were significantly less during the 3rd trimester than during the 2nd trimester and when compared to the non-pregnant controls. No differences were found in any of the measures between the pregnant women in their 2nd trimesters and the control group. When comparing the pregnant fallers, non-fallers, and controls, reaction time was not different between the pregnant fallers, pregnant non-fallers, and non-pregnant controls. Initial sway, sway velocity, and total sway were less in the pregnant fallers when compared to the pregnant non-fallers and controls. No differences were noted between the latter two groups. Thirty-one pregnant subjects reported exercise participation. Sedentary women were more likely to fall than active women. Pregnant workers were not more likely to fall than pregnant women who were not employed. **Applications for NIOSH:** In the workplace, both employers and employees should be aware that dynamic balance in reaction to a perturbation, such as a trip or a slip, may be significantly impaired in the third trimester of pregnancy. Exercise participation may help to reduce the incidence of falls.

Highlights/Significant Findings

Dynamic postural stability in response to a perturbation is significantly impaired during the third trimester of pregnancy. While reaction time did not increase during the third trimester, the amount of sway immediately following the perturbation, velocity of sway, and the total amount of sway were significantly lower during the third trimester.

Fifty-six percent of the pregnant women in the study experienced a fall during their pregnancies This value was determined from 18 of the 32 women for whom we have complete data. A total of 28 falls were reported. Dunning et al. [3], in a retrospective study which surveyed women post-partum about whether or not they had fallen while pregnant, reported that approximately 27% of pregnant women fall. We collected our data over the course of the women's pregnancies, not following them. The rate of falls in pregnant women may be much higher than previously reported.

Pregnant women who reported a fall demonstrated impaired dynamic stability when compared to pregnant women who did not fall as well as the non-pregnant controls. Specifically, the amount of sway immediately following the perturbation, velocity of sway, and the total amount of sway were significantly lower in the pregnant women who reported falling. Reaction time was not different between the groups.

The majority of the pregnant women reported participation in exercise during their pregnancies. However, all of the sedentary pregnant women stated that they experienced a fall while pregnant, while slightly less than half of the pregnant exercisers fell (11 out of 25). Exercise may play a role in preventing falls in pregnant women.

Translation of Findings

Pregnant women are at a high risk for falling in the workplace as over half of the pregnant women in this study reported a fall. Dynamic balance in response to a perturbation is impaired during the third trimester of pregnancy. Employers should take extra precaution to ensure that a pregnant woman does not have to encounter a potentially dangerous situation such as a wet or uneven floor during her third trimester. Participation in a low-impact exercise such as walking or yoga may help to prevent falls in pregnant women; therefore, pregnant women should be encouraged to exercise, particularly if such classes are offered through an employer-sponsored wellness program.

Outcomes/Relevance/Impact

There are several potential outcomes to this study. Pregnant women in their third trimester demonstrated impaired postural control in response to a perturbation compared to when they were in their second trimesters. When they were in their second trimesters, their postural control was not different than non-pregnant controls. This has the potential to impact the manner in which pregnant women are treated in the workplace. Employers should be aware that women in advanced stages of pregnancy may be more likely to fall in response to a trip or a slip and take extra precaution to remove the women from encountering such situations.

The women who fell in this study demonstrated impaired balance in response to a postural perturbation compared to the women did not fall. We believe that the likelihood of falling is more intrinsic (i.e. due to subject characteristics) rather than extrinsic (i.e. due to environmental characteristics). Based on our subject surveys of employment, types of shoes commonly worn, fall risk factors inside the home and at work, etc., we believe that all pregnant women encountered similar risk-factors to tripping and slipping. Therefore, we do not believe that the women who fell encountered more risks of falling than the women who did not fall. Rather, we believe that the ability to recover from a slip or a trip is intrinsically less in the women who fell. At this point, however, we cannot pinpoint exactly what these intrinsic factors are. Because exercise seemed to have a protective effect against falls, we believe that muscle strength may play a role. We did not test proprioceptive capabilities. They may certainly play a role in fall incidence. Reaction time was not different between the fallers and non-fallers so we do not believe that it is a factor.

Scientific Report

Background

Pregnant women are at high risk for injuries due to falls. In general, pregnant women fall at the same rate (27%) as women over the age of 70 years (28%) [3]. Falls are the leading cause of emergency department hospital admissions in pregnancy [3]. Given that more than 70% of pregnant women are employed [5], the impact of falls at work is potentially very high. However, the risk factors for falls in pregnant women are unknown. This study addresses this issue. This work is relevant to the National Occupational Research Agenda (NORA) [6] with "Traumatic Injuries", "Special Populations at Risk", and "Pregnancy Abnormalities" being specifically cited [6].

Falls

Falls in the Workplace

Falls are a significant problem in the workplace. The US Bureau of Labor Statistics reported 1,436,194 workplace injuries occurred in 2002 [7]. Approximately 173,900 falls occurred in the workplace in which the worker fell to a lower level [7], while an additional 350,000 workers fell but landed on the same level [7]. Almost 96,200 workers reported a slip, trip, or loss of balance that did not result in a fall but resulted in an injury requiring time away from work [7]. In the service and retail trade industries, falls constituted approximately 24% of the total workplace injuries [7].

Falls during Pregnancy

Trauma and/or accidental injury complicate 6-7% of all pregnancies [8]. Accidental falls were cited as the reason behind 17-39% of all trauma related emergency room visits or hospital admissions to pregnant women [8-14]. Falls during pregnancy not only result in fractures, joint sprains, muscle strains, head injury, and rupture to internal organs, but also placental separation, uterine rupture, and occasionally maternal or fetal death [9, 14-19].

All Pennsylvania (PA) resident women aged 15-44 yrs with co-existent pregnancy and injury related diagnoses were identified from the 1995 PA acute hospital discharge data [20]. Falls were the second leading cause of injury to the pregnant women (26.4%), behind only motor vehicle accidents (33.6%) [20]. Compared to non-pregnant women of the same ages, pregnant women were 2.33 times as likely to fall [20]. A study performed at a large community hospital in

North Carolina indicated that 21.8% of the trauma cases to pregnant women were associated with falls, while 54.6% were secondary to motor vehicle accidents, 22.3% to domestic abuse and assaults, and 13% to burns, puncture wounds, and animal bites [8]. The majority of the falls occurred between 25-30 weeks of gestation [8].

The number of hospital admissions for falls may not accurately represent the true incidence of falls in pregnant women. Dunning et al. [3] surveyed approximately four thousand women who gave birth within the eight weeks prior to the survey in the greater Cincinnati metropolitan area. One thousand seventy women, or 26.8% of the study sample, reported a fall, and 9.5% reported that they fell on multiple occasions. Sixteen percent (630 women) of the sample population reported that they were injured during the fall. Only 10.0% (402 women) sought medical attention. Sixteen women reported that they experienced premature labor or delivery as a result of the fall [3]. The women were also questioned about the external factors that were related to the fall. More than 40% of the women stated that they were ascending or descending stairs at the time of the fall. Other factors included: slippery or uneven surfaces, carrying an object or a young child, hurrying, shoes with loose or slippery soles, and reaching for an object [3].

Fetal Injuries and Deaths resulting from Falls

Injury to a pregnant woman is all the more concerning because harm to the mother may result in fetal injury or death. In cases where a maternal injury resulted in early or threatened labor, 80% of the injuries were accidental or unintentional [20]. Of these injuries, 30% of the cases were attributable to falls [20]. Weiss et al. studied the fetal death certificates from 1995-1997 for 16 states, which accounted for 55% of US live births and approximately 15,000 fetal death registrations each year [14]. During this time, 3.7 fetal deaths were reported per 100,000 live births [14]. Motor vehicle crashes were the leading cause of fetal trauma (82% of cases), followed by firearm injuries (6%) and falls (3%) [8]. Another study indicated that 14.3% of the fetal deaths related to trauma were the result of a fall [8].

Falls by Pregnant Women in the Workplace

An epidemiological study by Dunning et al. [3] determined the risk of work-related injury during pregnancy. Of the approximately four thousand study participants, 71.2% reported being employed during pregnancy [3]. The fall rate, 27%, was similar between the employed and unemployed women. Of the employed women, 13.1% fell at work, 76.5% fell elsewhere, and 10.6% fell both at work and elsewhere. The majority of work falls occurred from the 5th to the 7th month of gestation. The most common contributing factors for falls were stairs, slippery floors, hurrying, carrying an object, slick shoes, or high heels. Food service workers (13.2%), other service workers such as beauticians or housecleaners (12.8%), and teachers (10.2%) reported the highest rates of falls at work [3]. These fall rates are much higher than the occupational fall rate of 1.3 in 1000 for non-pregnant female workers under the ages of 45 years [21]. The Bureau of Labor Statistics reports a 0.32% rate of missed work due to a fall at work for all occupations and genders (USBLS 2004), while the study by Kemmlert and Lunholm (1998) reported a rate of 0.7% of missed work days in pregnant women due to a fall at work. If these data were extrapolated to include all pregnant American women, work falls during pregnancy would result in at least 99,525 missed work days and $11,445,375 in lost wages annually [3].

Physiological and Biomechanical Changes during Pregnancy

Physiological Alterations associated with Pregnancy

A number of anatomical, physiological, and hormonal changes that occur during pregnancy may be related to the increased incidence of falls in pregnant women, although the specific risk factors are unknown. Pregnant women experience weight gain, an increased volume and weight of the uterus, increased ligament laxity, increased interstitial fluid that results in swelling of the extremities, decreased kinesthetic sense and coordination, altered biomechanics, altered position of the center of gravity, increased spinal lordosis, and changes in mechanical loading and joint kinetics [3, 22, 23].

The total weight gain during pregnancy averages 109 N $\pm$ 48 N [22-24]. During the first trimester, the average weight gain is 11.1 N, whereas the average weight gain during the second and third trimesters is 48 N and 50 N, respectively. The rate of weight gain during the last trimester was found to be highly variable between patients. In a normal, healthy pregnancy, 45% of the weight gain is related to the fetal weight, 10% is due to uterine growth, 12% is related to breast growth, 15% is protein retention, and the remaining 18% is interstitial water [23, 24]. In addition, more than half of patients with toxemia experience twice the average weight gain of healthy patients during pregnancy [24].

The concentration of the hormone Relaxin increases dramatically during pregnancy to allow increased laxity of the pelvic joints [25]. However, Relaxin also affects the ligamentous laxity at other peripheral joints, such as the feet, teeth, fingers, knees, and hips [26, 27]. This loosening of the connective tissue, in combination with changes in mechanical loading patterns, may result in a higher risk of injury [23]. Postural control reflexes are elicited via intrafusal muscle spindles. If the muscle – tendon complex is lax, the slack in the system must be taken up first in order for the muscle spindles to be activated, resulting in an increased time delay prior to activation the reflex loop [28]. Thus, pregnant women may be at a higher risk for falls because of decreased neuromuscular control due to the presence of Relaxin.

The geometric constraints imposed by the enlarged uterus not only limit joint range of motions, but result in an anterior shift of the center of mass of the body [23]. During the first trimester, the fetus generally remains confined to the pelvis. By 20 weeks gestation, the uterus reaches umbilical level, starts to anteriorly protrude from the pelvis, limiting the range of motion at the hip [23, 29]. This limitation in hip range of motion alters movement kinematics as well as the kinetics of controlling the additional mass acquired in the trunk region [23, 29]

The muscles on the anterior abdomen exhibit excessive lengthening in order to accommodate the fetus, resulting in a dramatic decrease in abdominal muscle strength [30, 31]. This alteration in muscle length affects the force couple of the abdominal – lumbar spinal muscles, and is believed to be related to a significant increase in spinal lordosis and incidence of lower back pain during pregnancy [30-33]. However, other research has reported no change in lumbar spine angle, while still other authors report a decrease in lumbar spinal angle [34, 35]. One study reported that in the latter part of the third trimester, a 1.0-1.5 cm increase in height occurs and is attributed to increased intra-abdominal pressure providing increased support to the spinal column [35, 36].

The hormonal milieu that accompanies pregnancy results in marked alterations in neural function [4]. Eighty-two percent of pregnant women report difficulty in concentration, increased absentmindedness, and short-term memory loss [37]. Other neuropsychological investigations reveal deficits in concentration, attention, perception, and sensation, which the women perceive as memory failure [38, 39]. Mechanisms of the pregnancy-related impairment are attributed due to higher concentrations of estrogen, progesterone, glucocorticoids, and oxytocin [39]. These alternations in cognition may be related to the higher incidence of falls in pregnant women as compared to non-pregnant women.

Biomechanical Alterations associated with Pregnancy

There is a paucity of information in the literature on the biomechanical movement pattern changes that occur during pregnancy, as only two indexed studies were located. Foti, Davids, and Bagley [36] performed a gait analysis on fifteen pregnant women during the second half of the last trimester of pregnancy as well as one year post partum, with the intent of quantifying the "waddling gait" often seen during pregnancy. Increases were noted in maximum anterior pelvic tilt, maximum hip flexion, and maximum stance phase hip adduction, as well as the in joint kinetics at the ankle, knee, and hip [36]. Subjects experienced a pregnancy-related increase in height which was, on average, 1.2 cm [36]. This may increase the height of the center of mass, thus making the women more susceptible to a fall. When pregnant, the women also walked with a wider base of support, resulting in large side-to-side excursions of the center of mass. Despite this, no differences were seen in trunk tilt, pelvic obliquity, or pelvic rotation throughout the gait cycle, leading the authors to conclude the "waddling gait" could not be quantified via the torso kinematic parameters. The authors also noted that most gait parameters remained unchanged, despite increases in body mass, width, and mass distribution about the trunk [36]. Because of this, the demand placed on hip abductor, hip extensor, and ankle plantar flexor muscles may be increased during walking [36]. This may be a contributing factor in the higher incidence of muscle cramps seen during pregnancy [36]. Additionally, women who are inactive or have low muscle strength may be susceptible to a fall if the task-specific torque demands exceed the women's strength. An increase in hip abductor power during pregnancy was consistent with the increased use of the hip abductor muscles to maintain a normal gait pattern in the presence of increased body mass [36]. If the hip abductors are weak or become fatigued, the pregnant woman may have less neuromuscular control during gait, especially considering that the body mass is increased also.

The second study on gait in pregnancy investigated the transverse pelvic and thoracic rotations in regard to gait coordination [40]. The gait of pregnant women between 30 and 34 weeks of gestation and non-pregnant women was analyzed as subjects walked on a treadmill. The speed of the treadmill was gradually increased from 0.17 to 1.72 m/s. The amplitudes of the pelvic and thoracic rotations were somewhat reduced in the pregnant women, with significantly smaller intra-individual standard deviations [40]. At higher speeds, the pelvis and thorax of the non-pregnant women rotated out of phase with one another, whereas in the pregnant women, the pelvis and thorax were more in-phase, particularly at the faster walking velocities [40]. The change in torso mechanics may be related to the higher incidence of falls in pregnant women.

Biomechanics of Dynamic Stability

Several recent investigators have examined other aspects of postural stability during pregnancy [41-43]. Butler et al. [41] reported increased postural sway throughout pregnancy, as indicated by the increased length of the center of pressure (COP) path during quiet stance in pregnant women when compared to non-pregnant women. Similarly, Jang and colleagues found increased anterior-posterior and radial sway, no change in medial-lateral sway, and a wider preferred stance width in pregnant women during quiet stance when compared to non-pregnant women [43]. Jang et al. also reported that 13% of the pregnant women in their study experienced a fall during their pregnancies. Davies et al. [42] reported differences in global measures of balance between pregnant women while in labor and non-pregnant women. No studies have assessed postural stability in response to a balance perturbation in pregnant women. However, studies on elderly individuals report longer reaction times and greater response amplitudes during translation perturbations of the support surface in elderly fallers when compared to elderly non-fallers [44-46].

Association between Level Walking and Fall Risk

Half of all of the falls by the elderly are reported to occur during locomotion [47]. When healthy older adults are compared to healthy young adults, step width variability, but not step length variability or step time variability, significantly discriminates between the two groups [48]. Stride-to-stride variability in stride length, speed, and double support was associated with risk of falling in elderly individuals [49]. Menz et al. report that elderly fallers have difficulty controlling trunk motion and maintaining a stable visual field when walking, as indicated by irregular pelvic and head accelerations [50].

The motion of the center of mass is indicative of fall risk. The motion of the whole-body center of mass is better able to distinguish elderly fallers from non fallers than markers representing the head, trunk, or pelvis [51]. Elderly fallers exhibited greater mediolateral displacement and peak velocities of the whole-body center of mass than do non-fallers [51, 52]. Mackinnon and Winter demonstrated that differences in the center of mass and center of pressure locations provide a valuable means for defining dynamic stability [53]. Given the pregnant women are anecdotally known to exhibit a "waddling gait", the mediolateral movement of the center of mass may put them at a higher risk for falls.

Association between Stair Locomotion and Fall Risk

The largest proportion of falls in public places occurs on stairs, and 4 out of 5 of these falls occur during stair descent [54, 55]. From a functional standpoint, stair ambulation is a more challenging task than walking on a level surface or on a ramp [56]. Older people often consider stair climbing and descent their most difficult physical performance tasks [57]. The demands that stairs place on the musculoskeletal and cardiovascular systems are compounded by the need for input from the somatosensory, visual, and vestibular systems at various stages in the task [58]. Vision and sensation may be particularly important because experimental studies have shown that the clearance between the swing foot and the stair edge can be as little as 3.7mm in healthy individuals [54, 59]. If a pregnant woman can no longer see the stairs because of a large abdomen, she may be at increased risk of falling. Additionally, in order to see the stair edge over her swollen abdomen, a pregnant woman may lean forward, causing her center of mass to be located closer to the edge of her base of support, and thus making her more susceptible to a fall.

Riener et al. report that the peak quadriceps (i.e. knee extension) moments are greater during stair descent than during either level walking or stair ascent [60]. At the time of the maximum knee extension moment, the knee power is negative, indicating an eccentric contraction of the quadriceps [60]. The required joint moments at the ankle and knee during stair descent are approximately 1.5-2 Nm per kg of body weight [58, 60, 61]. It is thus possible that the maximum eccentric strength of the knee is the limiting factor in pregnant women, whose body mass will increase by an average of 109 N over the course of the pregnancy [22-24].

Association between Postural Stability Variables and Fall Risk

Postural stability decreases with age, as indicated by increased reaction times and center of pressure movement in response to a translation perturbation in healthy older subjects compared to their young counterparts [44, 45]. Elderly individuals who have fallen exhibit reduced static balance than do non-fallers, as evidenced by the movement of the center of pressure [46]. Similarly, in response to a anterior-posterior translation perturbation, the displacement of the center of pressure is able to distinguish between the older individuals who have fallen and those who have not [44].

Normal aging increases the role of attention during standing and locomotion [45, 62, 63]. Redfern et al. found that age modulated the interference between a postural recovery to a perturbation and a simple reaction time task [45]. However, the authors reported that older subjects had shorter reaction times, but larger center of pressure movement response, in response to a translation perturbation [45].

Specific Aims

Specific Aim #1: Locomotor Kinematics

Determine the impact of pregnancy on kinematics variables related to balance and stability during gait and during stair ascent and descent during pregnancy.

Hypothesis #1

With advancing pregnancy, we hypothesize that the center of mass will move anteriorly with respect to the subject's base of support during level walking and stair locomotion.

Hypothesis # 2

We hypothesize that the mediolateral motion of the center of mass will increase during level walking and stair locomotion with advancing pregnancy.

Hypothesis # 3

With advancing pregnancy, we hypothesize that the step length, step width, and frontal plane range of motion will become more variable during level walking and stair locomotion.

Specific Aim #2: Locomotor Kinetics

Determine the impact of pregnancy on lower extremity joint torque magnitudes and timings (particularly the knee) during pregnancy.

Hypothesis # 4

We hypothesize that, with advancing pregnancy, the knee joint torques required for level walking will not change, but that knee joint torque during stair ascent and descent will increase.

Hypothesis # 5

We hypothesize that, with advancing pregnancy, the variability of the knee joint torques required for level walking, stair ascent and descent will increase.

Specific Aim # 3: Perturbation Responses

To determine if responses to postural perturbations during stance are altered with advancing stages of pregnancy.

Hypothesis # 6

We hypothesize that reaction time to an anterioposterior postural perturbation will increase with advancing stages of pregnancy.

Hypothesis # 7

We hypothesize that the magnitude of the postural response after an anterioposterior postural perturbation will increase with advancing stages of pregnancy.

Procedures

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 University of Pittsburgh Medical Center (UPMC) Womancare Research Registry in the beginning of their second trimester. Non-pregnant controls were recruited via flyers placed around the university community as well as advertisements placed on the University of Pittsburgh Institutional Review Board website. Each control participant was BMI-matched to a woman in the pregnant group based on the pregnant woman's self-reported pre-pregnancy mass. Control and pregnant participants were matched to within 2 kg/m^2 BMI.

Table 1: Subject Demographics

	Control Group (n = 40)	Pregnant Group (n = 41)	
Age (yrs)	26.5 ± 6.4	29.5 ± 4.9	
Height (cm)	165.8 ± 5.6	166.1 ± 6.6	
		Second trimester (n = 41)	Third Trimester (n = 29)
Weeks Pregnant		20.9 ± 1.2	35.8 ± 1.5
Mass (kg)	66.0 ± 8.9	74.7 ± 12.1	81.6 ± 11.0

Potential pregnant participants were excluded from the study if they were beyond their 20th week of pregnancy, were carrying more than one fetus, or if they had a history of any of the following: gestational diabetes, pre-eclampsia, toxemia, gestational hypertension, delivery of an older child prior to 36 weeks of gestation, 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 history of type I or type II diabetes or any other condition which could affect their sensation, a leg or foot fracture within the last five years, ankle or knee sprain within the last year, current back or knee pain, or a history of ligament rupture at the ankle or knee. Subjects were also excluded if they were a current smoker or if they currently took any medication which would affect their ability to balance. Subjects were excluded if they typically consumed more than one alcoholic drink per day.

Pregnant subjects made two visits to the University of Pittsburgh to participate in this study. Their first visit occurred in the middle of their second trimester. The average gestational age during the subjects' first data collection session was 20.9 ± 1.2 weeks. Their second visit occurred during the middle their third trimester at 35.8 ± 1.5 weeks. Twenty-nine of our 41 pregnant subjects participated in their second data collection session, meaning that 12 subjects did not continue with the study. The reasons were as follows: decision to withdraw from study (n = 4), delivery of the baby prior to 35 weeks (n = 4), pre-eclampsia or other complications to their pregnancy (n = 2), injuries sustained from a fall required the subject to be placed on bed rest (n = 1), and relocation to another part of the country (n = 1).

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, while six women reported that they were pregnant one time and one reported that she had been pregnant twice. No subject in either group reported being pregnant more than three times.

Control subjects participated in a single study visit. Because estrogen and progesterone are believed to influence movement patterns, flexibility, and dexterity (Lebrun 1994; Posthuma et al. 1987; Yack et al. 2003), data of the women in 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 (Tortora and Brabowski 2000). Additionally, by collecting data of the control group immediately following menses, we were certain that these women were not pregnant.

Methodology:

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. Following this, written informed consent approved by the University of Pittsburgh Institutional Review Board was obtained.

Each subject's blood pressure was measured to ensure that she was not hypertensive prior to testing. Each subject was also screened to make certain that she did not meet any of the contraindications to exercise stated by the American Academy of Obstetrics and Gynecology. The questionnaire used in this assessment is shown as *Appendix A*. Pregnant subjects completed a survey about any previous pregnancies and whether these pregnancies resulted in a live baby or a miscarriage or stillborn *(Appendix B)*. This questionnaire also contained questions about the subject's activity patterns and occupation. Additionally, the subject was asked whether or not she had fallen. If she answered yes, she was given another questionnaire to complete which provided us with details about each fall *(Appendix C)*.

Each subject changed into snug fitting shorts, a t-shirt, and comfortable lace-up shoes. Following this, her height and mass were obtained using a standard medical balance-beam scale and stadiometer. In order to calculate the location of the subject's center of mass, a series of 32 anthropetric measurements were made in the method described by Pavol, Owings, and Grabiner [64]. These measurements included lengths and circumferences of the extremities and the torso. The data collection form used for the anthropometric measurements is shown in *Appendix D*. These 32 factors were then entered into a series of regression equations in order for the locations of the segmental centers of mass to be calculated. The location of the whole-body center of mass was then determined from the calculated coordinates of the segmental centers of mass [65].

The gait analysis was performed using a 3D video analysis system and two force plates. The VICON 612 motion analysis system (VICON Motion Systems, Inc., Lake Forest, CA) is a three dimensional system that has eight high-speed (120 Hz) optical VICON M2 cameras surrounding a 10m walkway in the laboratory. Two Bertec force plates (Bertec Corp., Columbus, OH) were imbedded in the walkway. The video capture volume was 4.5x1.5x2.1 m^3. Calibration was done using the wand calibration method with mean residual errors in the range of 0.00123 – 0.00186 m (wand length = 0.914 m).

After the anthropometric measurements were obtained, 40 retroreflective markers were placed on the subject in accordance with a modified Helen Hayes marker set. A static, or anatomical, calibration was collected to determine the position of the joint centers and segmentally embedded coordinate systems with respect to the retroreflective markers, as described by Vaughan et al. [66]. The subject was then asked to walk at her freely chosen walking speed several times on the walkway in order to become accustomed to walking while wearing the marker set (Figure 1). Once the subject's speed was stabilized and a freely chosen walking speed was established, five good gait trials were collected (120 Hz). A trial was termed "good" when the subject contacted the force plate with no visible alteration in gait mechanics while walking at her established speed. The data collection frequency of the force plates was 1080 Hz. Subjects were given rest periods if needed.

Figure 1: A control subject participating in the gait assessment phase of the study.

Participants were asked to perform five trials of stair ascent and descent while still wearing the reflective markers. Subjects wore an upper torso and hip harness in order to protect against a fall. No straps were placed around the abdomen. Rest periods of at least one minute were provided between trials so that subjects did not become fatigued.

The staircase consisted of 4 stairs each with a rise of 20 cm and a run of 28 cm. The width of each step was 122 cm. A Bertec force plate was mounted within the second step of the staircase in order for the location of the center of pressure to be determined, as well as joint moments and joint forces to be calculated. The force plate was mounted to a wooden frame located beneath it. It was not mounted to the staircase in order to isolate mechanical vibration artifact as the subject traversed the staircase. The force plate and support box were structurally independent of the staircase. An illustration of a control subject performing stair ascent is shown in Figure 2.

Figure 2: A control subject participating in the stair ascent phase of the study.

After the trials were collected for both gait and the stair ascent and descent, the three-dimensional coordinates for each of the reflective markers were determined using the Direct Linear Transformation technique [67]. The path of each reflective marker was identified as a designated anatomical landmark, and the trials were truncated to include only the data from one left and right leg stride, beginning with heel strike on the force plate and ending with the subsequent heel strike. The timing of the initial heel strike was determined from the force plate data. Heel strike was defined as the point in time when the vertical ground reaction force exceeds 25 Newtons, or approximately 5% of body weight. The second heel strike, which was used as the end point of the stride, was determined by the sharp deceleration of the reflective marker on the heel. Ten points on either side of the stride were included to allow for data filtering. Kinematic data were filtered using a 4th order low-pass zero phase lag Butterworth filter with a cutoff frequency of 6 Hz.

Net joint forces and moments were determined by combining the kinematic, ground reaction force, and anthropometric data using an inverse dynamics technique [65]. Ground reaction forces were filtered using a 4th order low-pass zero phase lag Butterworth filter with a cutoff frequency of 50 Hz. Ground reaction forces were normalized to the subject's bodyweight in order to allow better comparison between subjects [65].

In order to assess stability during locomotion, several variables were calculated from the kinematic and kinetic data using a custom written program in Matlab (Mathworks Inc., Natick, MA): The position of the subject's center of mass with respect to their base of support was calculated (Specific Aim 1). We hypothesized that the center of mass would become more anterior with respect to their base of support as pregnancy advances. The variability of the gait parameters, as measured by the standard deviation between trials, was determined (Specific Aim 1). We hypothesized that the variability would increase with advancing stages of pregnancy, reflecting a decrease in neuromuscular control. The ankle, knee, and hip joint moments were calculated (Specific Aim 2). We hypothesized that, with advancing pregnancy, the required joint moments would increase.

Following the biomechanical evaluation, participants were escorted to the Jordan Balance Disorders Laboratory in the UPMC Eye and Ear Institute to complete the postural stability assessment. Postural stability was assessed using an Equitest® system (NeuroCom International, Inc., Clackamas, OR). The Equitest© system utilizes dynamic 18" x 18" dual force plates with translation capabilities to measure the COP movement.

Figure 3: A control subject participating in the postural stability phase of the study.

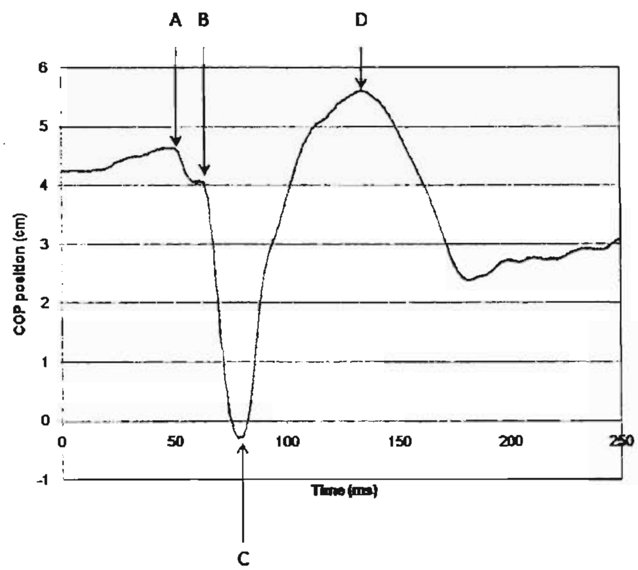
Subjects were asked to stand on the dual force plates. They were fitted in a chest and hip harness for protection against a fall (Figure 3). The harness was designed such that no straps were placed around the abdomen, only around the shoulders and upper thighs, thereby protecting the fetus should a loss of balance occur. Over the course of the study, no subject lost her balance such that she needed the harness during the dynamic stability testing. Subjects were instructed to stare at a blank video screen located at eye level in a visual surround in front of them, as well as to refrain from talking during the test.

A battery of tests was administered to assess their motor control in response to mild postural perturbations. Subjects received small, medium, and large anterior and posterior translations. Three trials of each condition were collected (100 Hz). In each condition, the velocity of translation was 15.24 $cm \cdot sec^{-1}$ and the time to maximum velocity was 50 ms. The magnitude of the perturbations was scaled to the subject's height, while maintaining the translation duration across all subjects. The formula used to calculate the translation magnitude was:

Translation Magnitude (inches) = X • (Subject's height (inches) x 72)

where X = 0.5 in the small perturbation trials, 1.25 in the medium perturbation trials, and 2.25 in the large perturbation trials. The durations of the translation of the small, medium, and large perturbations were 250 ms, 300 ms, and 400 ms, respectively. This protocol has been used to test frail, elderly subjects [45], as well as patients with vestibular disorders.

Several variables were calculated from these tests. All assessments were made on the anterior-posterior movement of the COP during the perturbation. Reaction time was defined as the time between the onset of the platform translation until the subject's COP was seen moving independently of the force plates. Initial sway was defined as the maximum initial COP movement resulting from the translation of the platform. Sway velocity was defined as the initial sway divided by the time from the onset of COP movement to the time of the initial sway. Total sway was defined as the total anterior-posterior movement of the center of pressure in response to the perturbation. A graphical depiction of these variables is shown in Figure 4. The data from each of the three trials at each magnitude in each direction for each subject were averaged to yield a representative value for that subject.



A = Onset of platform movement
B = Onset of subject reaction
C = Maximum posterior COP displacement
D = Maximum anterior COP displacement

Reaction time = Time at B – Time at A
Initial Sway = COP position at C – COP position at B
Total Sway = COP position at D – COP position at C
Sway Velocity = Initial Sway / (Time at C – Time at B)

Statistical Analyses

Specific Aim 1 was to determine the impact of pregnancy on kinematic variables related to balance and stability during gait and stair ascent and descent during pregnancy. We hypothesized that the center of mass would move anteriorly with respect to the base of support, that the mediolateral motion of the center of mass would increase, and that step length, step width, and frontal plane range of motion would become more variable.

For the pregnant group, a one-way repeated measures MANOVA was performed on the dependent variables ($\alpha = 0.05$). The independent variable for this analysis was trimester (2^{nd} and 3^{rd} trimesters). The primary dependent variables were maximum distance between the of center of mass with respect to base of support during walking and stair ambulation, variability of step length, step width, and frontal plane range of motion. Variability was calculated as the inter-trial standard deviation for each subject during each visit.

Additionally, to compare biomechanical stability of pregnant women to non-pregnant BMI-matched control participants, we performed paired t-tests for each dependent variable (position of center of mass with respect to base of support during walking and stair ambulation, and variability of step length, step width, and frontal plane range of motion). Comparisons were made between the control group and each visit of the pregnant group ($\alpha = 0.05$).

Specific Aim 2 was to determine the impact of pregnancy on lower extremity joint moments and timings (particular at the knee) during pregnancy. We hypothesized that, with advancing pregnancy, knee joint moments would not increase for level walking, but they would increase for stair ascent and descent. We also hypothesized that the variability of knee joint torques during level walking and stair locomotion would increase for advancing stages of pregnancy.

For the pregnant group, a one-way repeated measures MANOVA was performed on the dependent variables ($\alpha = 0.05$). The independent variable for this analysis was trimester (2^{nd} and 3^{rd} trimesters). The primary dependent variables were maximum stance-phase knee joint torque during level walking and stair ambulation, and intra-subject variability of knee joint torque in each activity. Variability was calculated as the inter-trial standard deviation for each subject during each visit.

Additionally, to compare biomechanical stability of pregnant women to non-pregnant BMI-matched control subjects, we performed paired t-tests for each dependent variable (maximum stance-phase knee joint torque during level walking and stair ambulation, and intra-subject variability of knee joint torque in each activity). Comparisons were made between the control group and each visit of the pregnant group ($\alpha = 0.05$).

Specific Aim 3 was to determine if responses to postural perturbations during stance were altered with advancing stages of pregnancy. We hypothesize that reaction time and the magnitude of the postural response after an anterior-posterior postural perturbation would increase with advancing stages of pregnancy.

Four dependent variables were measured in each trial: reaction time, initial sway, sway velocity, and total sway. Because the direction of sway was a factor of the direction of the perturbation, the absolute values of the initial sway and sway velocity variables were calculated to compare forward and backward perturbations. This was done for statistical comparisons only, but the data are presented in the results with their correct signs.

A mixed-model Analysis of Variance was performed on each of the four dependent variables. Subject was designated as a random factor, while trimester, direction, and magnitude were designated fixed factors. The statistical model was designed such that trimester (control, second, third) was nested within subject, direction (forward, backward) was nested within trimester, and magnitude (small, medium, large) was nested within direction. Specifically, our hierarchical model can be written as $Y_{ijklm} = \mu + subject_i + trimester_{j(i)} + direction_{k(ij)} + magnitude_{l(ijk)} + \varepsilon_{ijklm}$. The alpha level was set to 0.05 for each of the statistical analyses. For each of the statistical analyses, Tukey post-hoc tests were performed to determine if there were significant differences between the non-pregnant controls, 2nd trimester, and 3rd trimester subjects, as well as between the three perturbation magnitudes ($\alpha = 0.05$).

Additionally, to compare the dynamic balance of the pregnant fallers, pregnant non-fallers, and controls, a second mixed-model Analysis of Variance was performed on each of the four variables (reaction time, initial sway, sway velocity, and total sway). Subject was designated as a random factor, while fall group (pregnant non-faller, pregnant faller, or control), direction (forward, backward) and magnitude (small, medium, and large) were designated fixed factors. Our hierarchical model for this analysis can be written as $Y_{ijklm} = \mu + subject_i + \text{fall group}_{(i)} + direction_{k(ij)} + magnitude_{l(ijk)} + \varepsilon_{ijklm}$. The alpha level was set to 0.05 for each of the statistical analyses. For each of the statistical analyses, Tukey post-hoc tests were performed to determine where the significant differences were between the non-pregnant controls, pregnant women who reported a fall, and those who did not fall, as well as between the three perturbation magnitudes ($\alpha = 0.05$).

The effect of exercise on fall-risk in the pregnant women was examined. Pregnant subjects were categorized as participating in regular exercise at some point in their pregnancy or not. A Chi square analysis was performed to determine if non-fallers were more likely to be exercisers or conversely, if pregnant women who fell were more likely to be non-exercisers ($\alpha = 0.05$). The type of exercise performed was not designated in the Chi-square analysis.

The effect of employment on fall-risk in pregnant women was also examined. Pregnant subjects were categorized as being employed or not as well as whether or not they had fallen. A Chi square analysis was performed to determine if the pregnant women who were employed were more likely to have fallen or not ($\alpha = 0.05$). The type of employment was not designated in the Chi-square analysis.

Results and Discussion:

Twenty-nine of the 41 pregnant subjects (70.7%) were employed outside of the home. This is in accordance with the report by the DHHS that approximately 70% of pregnant women are employed [5]. Twelve women worked in office settings, two were teachers, two worked in daycare settings, and two were involved in cleaning houses. Four reported that they worked in research laboratories at the university. Other employments included: police officer, retail sales, nurse, aquatic director, cook, graduate student, and occupational therapist.

Eighteen of the pregnant subjects reported having at least one fall. A total of 28 falls were reported. One of the women did not participate in her 2nd study visit (i.e. third trimester) because of injuries sustained during a fall. A fall was defined as losing their balance such that another part of their body other than a foot touched the ground. Because fall data are not available on 11 of the 12 women who withdrew from the study, they are not included in the falls analysis. Therefore, these 18 women who reported falling represent 56% of the women in the sample.

Specifically, ten subjects reported falling one time, six subjects fell twice, and two subjects fell three times. No subject reported falling more than three times. Six of the falls occurred during the first trimester, 13 during the second trimester, and 9 during the third trimester. The locations of the falls included at home, on the stairs, on a public sidewalk or parking lot, at work, or in a public building. One fall involved falling more than four feet down, as the subject was on a staircase in her home and fell down 5 stairs. Four total falls involved falling down the stairs or from a curb. Four falls involved slipping on ice or a slick surface. Four falls involved carrying an object or a small child. Two falls involved tripping over an object in front of the subject (both 'objects' were small children), while 13 falls involved tripping when no other object was involved (i.e. poor toe clearance and hitting the toe of their swing leg on the ground). The shoes worn by the subjects at the time of the fall were as follows: barefoot (n = 2), socks (n = 4), slippers (n = 1), flat dress shoes (n = 3), flip-flops (n = 4), clogs (n = 1), athletic shoes (n = 9), and boots (n = 4).

None of the falls required hospitalization, although two falls necessitated treatment in the hospital emergency room, and one fall required treatment at the doctor's office. No broken bones were reported due to the falls. The injuries sustained in the falls that required medical treatment were as follows: sprained ankle (n = 2), sprained knee (n = 1), and laceration on the knee (n = 1). The one subject who could not complete her 2nd study visit because of a fall sustained one of the sprained ankles. Additionally, she was placed on bed rest because of suspicion of a tear in the amniotic membrane. No subject delivered prematurely due to a fall.

Trimester Comparison

Movement of the Center of Mass

One of the primary purposes of this study was to quantify the "waddling" gait commonly exhibited by pregnant women. We hypothesized that the frontal plane movement of the center of mass would be greater in the pregnant women and would increase between the second and third trimesters (Specific Aim 1). After further consideration, we also decided to quantify the amount of frontal plane movement at C7 during gait. We thought that perhaps the side to side movement occurred superior to the center of mass, and would thus be more reflected in the movement of C7. We also believed that a woman's height would affect the absolute amount of side to side movement such that taller women would have a greater distance of movement but perhaps the same amount relative to her height. Therefore, we normalized each subject's mediolateral COM and C7 movement to her height to better compare between subjects. The data are shown in Figure 5.

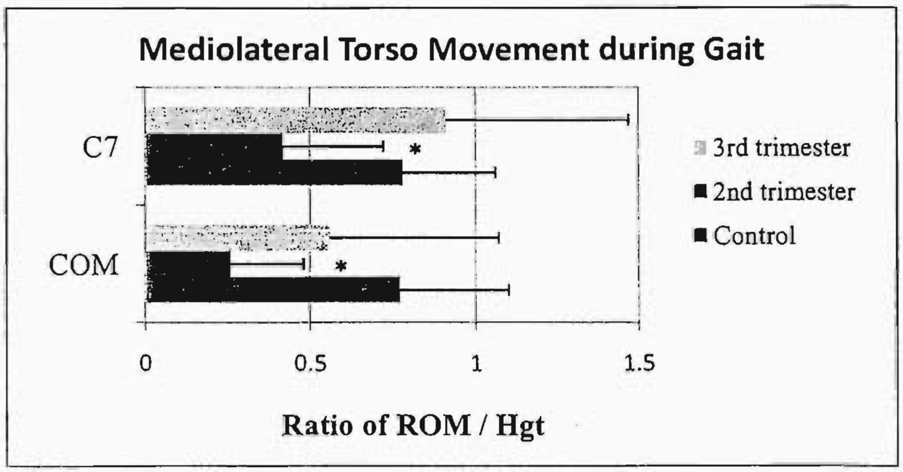


Figure 5: Mediolateral movement of C7 and the COM during a complete gait cycle. Results are presented as normalized to the subjects height. * denotes differences between the pregnant women at 5 months and when they were in their third trimesters as well as the non-pregnant controls.

The mediolateral motion of the pregnant women when they were in their 2nd trimesters was significantly less than when they were in their 3rd trimesters ($p = 0.028$ for C7 and $p = 0.051$ for COM) as well as when compared to the non-pregnant control group ($p = 0.002$ for C7 and $p = 0.001$ for COM). This is true for the motion of both the motion of the COM as well as at C7.

We also examined the standard deviation of the mediolateral motion during gait (Specific Aim 1). We hypothesized that pregnant would result in a greater intrasubject variability and that this variability would be greater in advanced stages of pregnancy. Our results do not support our hypotheses. No differences were noted between the pregnant subjects and the controls or between the 2nd and 3rd trimesters of pregnancy in the mediolateral ROM of either the COM or C7. These results are shown in Table 2.

Table 2: Intrasubject variability of the mediolateral ROM of the COM and C7 during gait. Results are shown normalized to each individuals subject's height. The mean ± std dev are shown.

	COM variability	**C7 variability**
Control	0.171 ± 0.150	0.217 ± 0.142
2nd Trimester	0.038 ± 0.040	0.085 ± 0.061
3rd Trimester	0.179 ± 0.141	0.266 ± 0.327
p-value between pregnant and control	0.114	0.344
p-value between 2nd and 3rd trimesters	0.141	0.574

We also hypothesized that the width of the base of support (BoS) would be greater in the pregnant participants when compared to the controls, and would be further increased when the pregnant women were in their 3rd trimesters (Specific Aim 1). This value was calculated as the distance between the heel markers during the double support phase of gait, which is immediately after heel strike before contralateral toe-off. The BoS of our control group was significantly less than our pregnant group ($p < 0.05$). However, no differences were noted in our pregnant women between their 2nd and 3rd trimesters ($p = 0.793$). The data are illustrated in Figure 6.

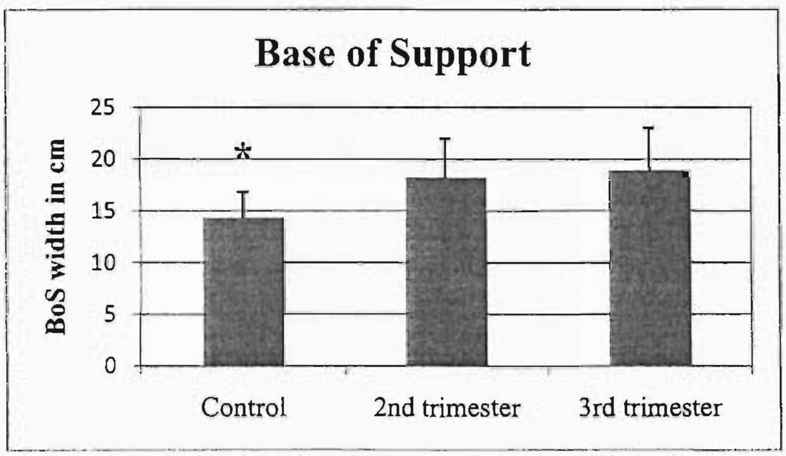


Figure 6: The width of the base of support during gait in the pregnant subjects and the non-pregnant controls. The base of support was significantly greater during pregnancy ($p < 0.05$).

Gait kinetics

The flexion and extension knee joint moments during the stance phase of gait were compared in the pregnant women between their 2nd and 3rd trimesters (Specific Aim 2). Additionally, the knee joint moments of the control group were compared against those of the pregnant women in each of their trimesters. The knee flexion and extension moments are shown in Table 3. We hypothesized that the knee moments would increase with advancing stages of pregnancy because of the concomitant increase in body mass.

The largest knee flexion moment during stance occurred just after heel strike in all of the subjects. Contrary to our hypotheses, the flexion moments of the control group were greater than those of the pregnant group ($p < 0.001$). There were no differences between the flexion moments of the pregnant women between their 2nd and 3rd trimesters ($p = 0.92$), despite the approximate 4.0 kg gain in body mass.

The maximum knee extension moment in gait occurred after the knee flexion moment when the quadriceps are eccentrically active to control the landing phase of gait, and subsequently when the muscle group is concentrically extending the knee in mid-stance. The knee extension moments were significantly greater in the control group than in the pregnant group, and no differences were noted in the pregnant women as they advanced from their 2nd trimester to their 3rd trimester.

Table 3: Knee joint moments in the pregnant and non-pregnant women. The data shown are mean ± standard deviation.

	Knee Flexion Moment (Nm)*	Knee Extension Moment (Nm)*	Variability of the Knee Flexion Moment*	Variability of the Knee Extension Moment
Control	533.5 ± 242.1	864.1 ± 349.0	85.3 ± 73.6	65.2 ± 18.2
2nd Trimester	379.1 ± 74.6	592.4 ± 262.5	49.3 ± 34.5	73.5 ± 27.0
3rd Trimester	364.3 ± 149.1	547.9 ± 195.6	33.0 ± 16.9	85.9 ± 31.4

* Denotes significant differences between the pregnant subjects and the non-pregnant controls.

We also hypothesized that the within-subject variability of the knee joint moments would be more variable in the pregnant group and that the amount of variability would increase with advancing pregnancy. Variability was calculated as the standard deviation between trials for each subject within each study visit.

The variability of the knee flexion moment was greater in the control group than in the pregnant groups, which was contrary to our hypothesis ($p < 0.001$). Additionally, the variability in the pregnant women between their 2nd and 3rd trimesters did not increase ($p = 0.295$). These data are shown in Table 3.

Our hypotheses were supported by the data of the variability of the knee extension moment when the pregnant women were compared to the control women. The variability of the control subjects was significantly less than the 3rd trimester data of the pregnant group ($p = 0.004$), but it was not different than the variability of the 2nd trimester visit ($p = 0.357$). However, the variability of the knee extension moment of the pregnant group in their 3rd trimester was not significantly greater from when the women were in their 2nd trimesters ($p = 0.116$).

We hypothesized that the knee joint moment variability would increase for several reasons: the hormonal alterations that accompany pregnancy are said to slow nerve function, and the greater body mass would be harder to control[4, 23]. Both of these factors would negatively impact a woman's motor control of her body as her pregnancy advanced.

Dynamic postural stability

Reaction time, initial sway, sway velocity, and total sway were compared between the pregnant women in their 2nd and 3rd trimesters and the non-pregnant control women (Specific Aim 3). Reaction time was not significantly different between the non-pregnant women (124.1 ± 18.6 ms) and the women in the 2nd and 3rd trimesters of pregnancy ($p = 0.062$). The average reaction time for the women in their 2nd trimester was 124.9 ± 14.7 ms, while it was 127.6 ± 30.8 ms for the women in their final trimester. Reaction time also did not differ between the forward and backward perturbations; however, it was significantly shorter for the longer perturbations (122.6 ± 24.5 ms) than for the small and medium perturbations (127.5 ± 17.9 ms, and 126.5 ± 18.9 ms, respectively). Reaction time data for each of the perturbation magnitudes in each direction for each group are shown in Table 4.

Table 4: Reaction Times (ms) for the non-pregnant controls and the pregnant women in their second and third trimesters for the forward and backward perturbations at each of the three perturbation magnitudes. The data shown are mean ± standard deviation.

Trimester	**Direction**	**Magnitude**	**Reaction Time (ms)**
$p = 0.062$	*$p = 0.447$*	*$p = 0.004$*	
Non-pregnant Controls 124.1 ± 18.6 ms	Forward 125.6 ± 21.4	Small	128.3 ± 13.8
		Medium	123.6 ± 12.4
		Large	124.9 ± 32.0
	Backward 122.5 ± 15.2	Small	125.4 ± 16.9
		Medium	122.6 ± 13.8
		Large	119.4 ± 14.3
2nd Trimester 124.9 ± 14.7 ms	Forward 124.8 ± 12.3	Small	126.9 ± 14.6
		Medium	126.8 ± 10.5
		Large	120.6 ± 10.3
	Backward 125.0 ± 16.7	Small	127.1 ± 21.7
		Medium	125.3 ± 13.8
		Large	122.6 ± 13.3
3rd Trimester 127.6 ± 30.8 ms	Forward 127.3 ± 27.6	Small	128.2 ± 21.0
		Medium	131.2 ± 40.8
		Large	122.5 ± 12.6
	Backward 128.0 ± 33.8	Small	127.4 ± 18.3
		Medium	126.9 ± 13.8
		Large	129.6 ± 54.1

Initial sway, or the amount of COP movement in initial response to the perturbation, was significantly less in the pregnant subjects during their 3rd trimester (4.22 ± 1.83 cm) than in their 2nd trimester or in the control group ($p < 0.001$). The initial sway was not different between the women in their 2nd trimester (4.58 ± 1.81 cm) and the non-pregnant control women (4.47 ± 1.96 cm). The initial sway was significantly greater in response to a backward perturbation than a forward perturbation (4.51 ± 1.93 cm and 4.37 ± 1.81 cm , respectively; $p < 0.001$). Additionally, the large slides resulted in significantly greater initial sway (5.95 ± 1.24 cm) than the medium slides (4.69 ± 1.34 cm), which were in turn greater than the small slides (2.67 ± 1.33 cm) ($p < 0.001$). An illustration of the initial sway for each group in each direction/magnitude combination is shown in Figure 7.

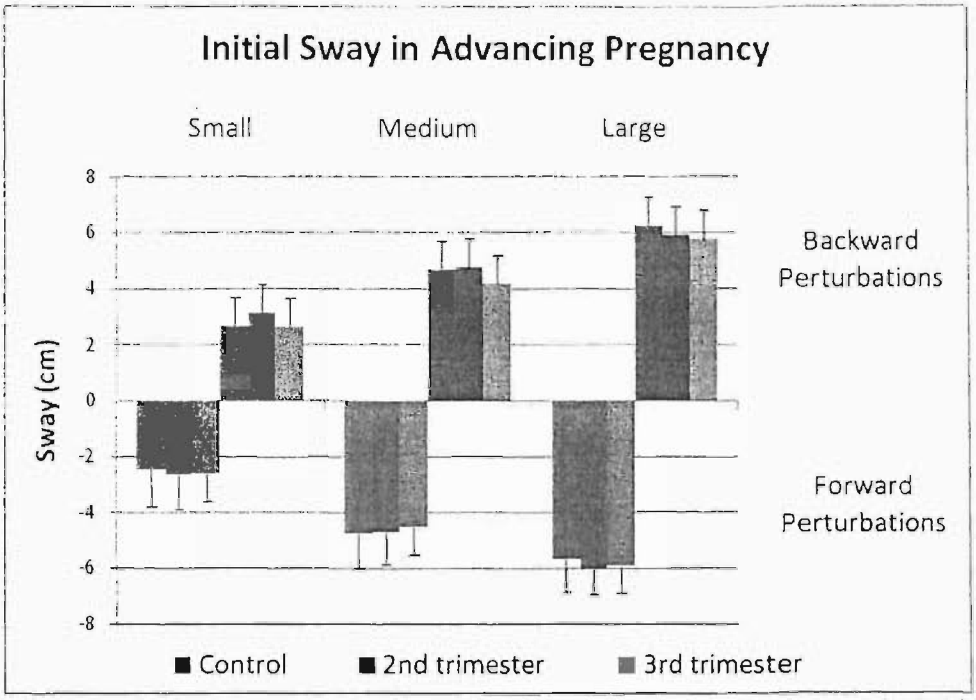


Figure 7: Initial Sway in response to the forward and backward perturbations. The initial sway was significantly different between groups (control, 2nd trimester, and 3rd trimester) ($p < 0.001$), as well as between forward and backward perturbations ($p = 0.002$) and the small, medium, and large perturbations ($p < 0.001$).

The sway velocity was similarly affected between groups. The women in their third trimesters demonstrated significantly less sway velocity (25.7 ± 13.0 cm/s) than when they were in their 2nd trimesters (29.6 ± 13.3 cm/s) and when compared to the non-pregnant control group (29.9 ± 14.3 cm/s) ($p < 0.001$). The sway velocity of the pregnant women in their 2nd trimester and the non-pregnant women were not significantly different from one another. The velocity of sway was significantly greater for the forward perturbations (29.6 ± 14.2 cm/s) than for the backward perturbations (27.8 ± 13.2 cm/s) ($p < 0.001$). Also, the velocity of sway was greater for the large perturbations (35.3 ± 11.9 cm/s) than for the medium and small perturbations, and the sway velocity was greater in the medium (31.7 ± 12.1 cm/s) than in the small trials (19.0 ± 11.5 cm/s) ($p < 0.001$). An illustration of the sway velocity for each group in each direction/magnitude combination is shown in Figure 8.

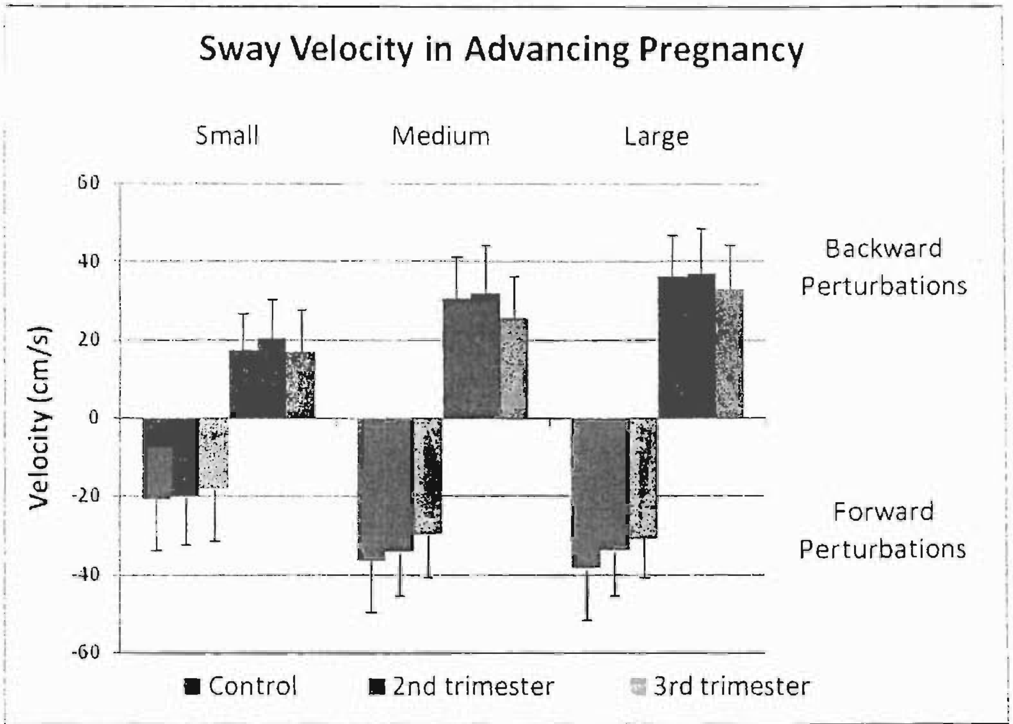


Figure 8: Sway velocity in response to sliding perturbations. The sway velocity was significantly different between groups (control, 2nd trimester, and 3rd trimester) ($p < 0.001$), as well as between forward and backward perturbations ($p < 0.001$) and the small, medium, and large perturbations ($p < 0.001$).

The final variable that we assessed was the total amount of fore-aft COP movement, or total sway. The women in their 3rd trimester exhibited significantly less sway (6.19 ± 2.76 cm) than when they were in their 2nd trimester (7.17 ± 3.02 cm) and less than the control group (7.11 ± 3.39 cm) ($p < 0.001$). The forward perturbations elicited more total sway than the backward perturbations (7.02 ± 3.26 cm and 6.76 ± 3.00 cm, respectively, $p = 0.016$). Also, the large perturbations elicited more total sway (8.45 ± 2.53 cm) than the medium and small perturbations, and the medium perturbations (7.31 ± 2.85 cm) resulted in greater total sway than the small perturbations (4.91 ± 2.90 cm) ($p < 0.001$). An illustration of the total sway for each group in each direction/magnitude combination is shown in Figure 9.

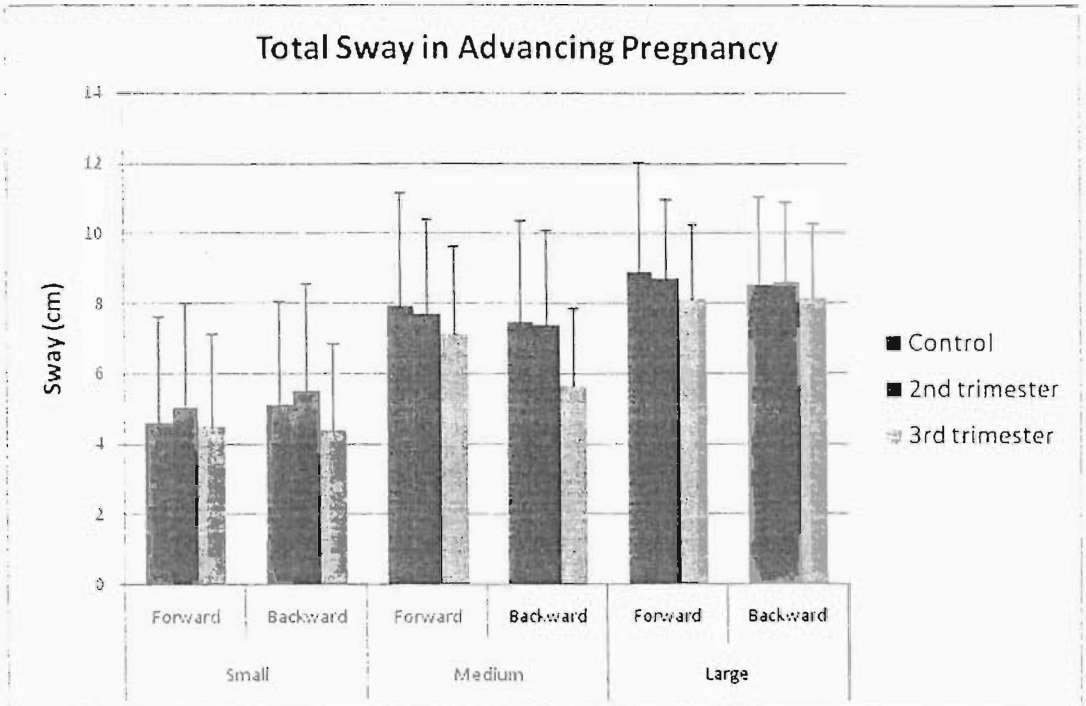


Figure 9: Total COP sway in response to sliding perturbations. The total sway was significantly different between groups (control, 2nd trimester, and 3rd trimester) ($p < 0.001$), as well as between forward and backward perturbations ($p = 0.014$) and the small, medium, and large perturbations ($p < 0.001$).

Reaction time to the sliding perturbation was not significantly longer during pregnancy, which was contrary to our hypothesis. We expected to see a decreased reaction time for two reasons: decreased nerve conduction velocity [38] and increased slack in the muscle-tendon complex. The concentration of the hormone Relaxin increases dramatically during pregnancy to allow increased laxity of the pelvic joints [25]. However, Relaxin also affects the ligamentous laxity at other peripheral joints [26, 27]. In the muscle-tendon complex is lax, the slack in the system must be taken up first in order for the muscle spindles to be activated, resulting in an increased time delay prior to activation of the reflex loop [28].

Initial sway, or the amount of anterior-posterior COP movement in response to the sliding perturbation, was not different between the control group and the pregnant women in their 2nd trimester. However, initial sway was significantly decreased during the 3rd trimester, contrary to our hypothesis. We expected the sway to increase for a number of reasons. The hormonal changes which accompany pregnancy are said to result in slower reflexes and greater flexibility, providing less control and more sway. The increased body weight in pregnancy should also be harder to control, resulting in more sway. Butler et al. [41] and Jang et al. [43] report greater anterior-posterior COP movement in quiet stance in pregnant women. Additionally, elderly individuals with a history of falling demonstrate more COP sway in response to a sliding perturbation than do age-matched counterparts with no history of falling [45].

To our knowledge, this is the first study to assess dynamic postural stability in response to a sliding perturbation in pregnant women. In their third trimesters, the pregnant women demonstrated increased rigidity, as evidenced by the lack of sway following the perturbation.

We have no data on whether or not a subject had a fear of falling. However, for the purposes of this discussion, we performed a post-hoc test to determine if subjects became rigid following the first perturbation. Three trials per condition per magnitude were performed in each direction. We examined the data from each of the three trials in each magnitude in each direction to determine if the pregnant women in their 3rd trimester became significantly more rigid following the first perturbation while perhaps the non-pregnant controls and the women in their 2nd trimesters did not demonstrate significant differences between trials.

Indeed, the initial sway in the first trial was significantly greater than in trials 2 and 3 ($p < 0.001$). Trials 2 and 3 were not significantly different ($p = 0.71$). However, this was seen in all groups of subjects, not just the women in their 3rd trimesters. The interaction between the group (control, 2nd trimester, and 3rd trimester) and trial number did not near significance ($p = 0.917$). Therefore, the reason why the women in their 3rd trimester experience less initial sway is not that they experience the first trial and then they get very rigid in response to the latter two trials because all three groups have greater sway on trial 1 than on trials 2 and 3.

A similar effect is seen with the measures of sway velocity and total COP sway between the pregnant women in their third trimesters and the other two groups. In the latter stages of pregnancy, the subjects exhibited less sway velocity and less total COP movement. Sway velocity was calculated as the initial sway divided by the onset of reaction to the time of the maximum COP deflection. We did not calculate the time between the onset of reaction and maximum initial sway. However, given that the initial sway was less in this group when compared to the other two groups, it is not surprising that the velocity of this movement is also less.

We conducted a post-hoc analysis similar to that described above to determine if these results could have been affected by the trial number in the condition (i.e. in each direction at each magnitude). As seen above, there was an effect of the trial order. The largest sway velocity and largest total COP movement occurred in the first trial ($p < 0.001$). There were no differences between trials 2 and 3 for any of the three groups. Additionally, the group x trial interaction was not significant ($p = 0.995$ for sway velocity and $p = .0.610$ for total COP sway); therefore, the women in their 3rd trimesters were not influenced by the first trial any more so than when they were in their 2nd trimester or when compared to the control group.

Anthropometric factors may play a factor in the COP alterations seen in the 3rd trimester. Subjects, on average, gained approximately seven kilograms between the second and third trimesters. The average waist circumference in the 2nd trimester was 94.1 cm, and 103.8 cm in the third trimester, an increase almost 10 cm.

No other studies have reported dynamic postural stability in pregnant women. Butler et al. [41] and Jang et al. [43] found increased anterior-posterior COP sway during quiet stance in pregnant women when compared to non-pregnant women. Jang et al. also reported that the length of the path of the COP in the anterior-posterior direction increased with advancing pregnancy [43]. However, the ability of a static measure to predict dynamic balance of a pregnant population is not clear. Based on our results, it does not appear that static measures of balance are predictive of dynamic postural stability.

Several studies have reported gait mechanics during pregnancy [36, 40]. Wu et al. [40] evaluated pelvic and thoracic torso rotations and gait coordination of women who were between 30 and 34 weeks gestation as compared to non-pregnant women. The amplitudes of both the pelvic and thoracic rotations were reduced in the pregnant women. Additionally, while the pelvis and thorax of the non-pregnant women rotated out of phase with one another, the opposite was seen in the pregnant group such that the torso rotated as a single unit with the pelvis and thorax moving in phase with one another. Wu and colleagues speculated that this change in mechanics may be related to the higher incidence of falls in pregnant women [40]. Perhaps this alteration in torso mechanics is related to the findings in our study such that the alteration in torso mechanics is indicative of the increased rigidity seen in the women in their 3rd trimester in the current study. This change in torso mechanics may be due to changes in torso anthropometry. The average pregnant woman in our study gained approximately seven kg in mass and ten cm in waist circumference between their 2nd and 3rd trimesters.

Comparison of Pregnant Fallers, Non-Fallers, and Non-Pregnant Controls
Gait kinetics

Although the comparison between fallers and non-fallers was not part of our original specific aims, enough of the pregnant women fell so that a comparison between fallers and non-fallers could be made. We hypothesized that the fallers would exhibit greater knee flexion moments and greater variability than the non-fallers, and that all pregnant women would exhibit greater variability than the non-pregnant women in the control group. The knee flexion and extension moments are shown in Table 5.

As in the trimester comparison, the largest knee flexion moment during stance occurred just after heel strike in all of the subjects. The flexion moments of the control group were greater than those of the pregnant group ($p < 0.001$). There were no differences between the flexion moments of the pregnant fallers and non-fallers ($p = 0.22$). The knee extension moments were significantly greater in the control group than in either the pregnant fallers and non-fallers ($p < 0.001$). Additionally, the pregnant non-fallers exhibited greater knee extension moment than did the fallers ($p = 0.04$).

Table 5: Knee joint moments in the pregnant fallers, non-fallers, and non-pregnant controls. The data shown are mean ± standard deviation.

	Knee Flexion Moment (Nm)*	Knee Extension Moment (Nm)*#	Variability of the Knee Flexion Moment*	Variability of the Knee Extension Moment
Control	533.5 ± 242.9	864.2 ± 349.1	85.3 ± 73.7	65.2 ± 18.2
Pregnant Non-Fallers	335.8 ± 103.6	657.7 ± 228.3	42.3 ± 26.7	86.5 ± 31.6
Pregnant-Fallers	403.3 ± 112.3	496.2 ± 213.9	41.7 ± 31.2	72.7 ± 26.2

* Denotes significant differences between the pregnant subjects and the non-pregnant controls.
# Denotes significant differences between the pregnant fallers and non-fallers.

The variability of the knee flexion moment was greater in the control group than in the pregnant group, which was contrary to our hypothesis ($p < 0.001$). Additionally, the variability of the knee flexion moment was not different between the pregnant fallers and non-fallers ($p = 0.99$). In terms of the knee extension moment, the variability was significantly greater in the pregnant group than in the control group ($p = 0.003$). The knee extension moment variability was not significantly different between the pregnant fallers and non-fallers, although it neared significance ($p = 0.06$).

Dynamic Stability

The dynamic stability of pregnant women who reported falling with those who did not fall and with the non-pregnant control group was examined by comparing the reaction time, initial sway, sway velocity, and total sway between the three groups. The reaction time was not significantly different between the three groups of subjects ($p = 0.091$). The reaction times were significantly different between small, medium, and large perturbations ($p = 0.018$), but not between the forward and backward perturbations ($p = 0.487$). The reaction times for each group of subjects for each magnitude and direction are shown in Table 6.

Table 6: Reaction Times (ms) for the non-pregnant controls and the pregnant fallers and non-fallers for the forward and backward perturbations at each of the three perturbation magnitudes. The data shown are mean ± standard deviation.

Trimester	Direction	Magnitude	Reaction Time (ms)
p = 0.091	*p = 0.487*	*p = 0.018*	
Non-pregnant Controls 124.1 ± 18.6 ms	Forward 125.6 ± 21.4	Small	128.3 ± 13.8
		Medium	123.6 ± 12.4
		Large	124.9 ± 32.0
	Backward 122.5 ± 15.2	Small	125.4 ± 16.9
		Medium	122.6 ± 13.8
		Large	119.4 ± 14.3
Pregnant Non-Fallers 126.8 ± 25.9 ms	Forward 127.2 ± 22.6	Small	129.4 ± 13.5
		Medium	130.4 ± 34.2
		Large	121.6 ± 11.8
	Backward 126.4 ± 29.0	Small	127.5 ± 16.7
		Medium	124.2 ± 13.0
		Large	127.5 ± 45.5
Pregnant Fallers 124.8 ± 17.7 ms	Forward 124.7 ± 17.6	Small	126.0 ± 23.7
		Medium	127.2 ± 13.7
		Large	120.9 ± 13.1
	Backward 125.0 ± 17.9	Small	125.6 ± 23.5
		Medium	128.6 ± 14.8
		Large	120.7 ± 13.1

The initial sway was significantly less in the pregnant fallers when compared to the pregnant non-fallers and the controls ($p < 0.001$). No differences were noted between the latter two groups. In this comparison, the amount of sway was significantly different between the small, medium, and large perturbations ($p < 0.001$), but not between the forward and backward perturbations ($p = 0.131$). The sway velocity and the total sway were significantly less in the pregnant fallers when compared to their non-faller counterparts as well as the control participants (both p-values < 0.001). Similarly, both the sway velocity and total sway were significantly different between the forward and backward perturbations as well as the small, medium, and large slides ($p < 0.05$). The initial sway, sway velocity, and total sway data are shown in Figures 10, 11, and 12, respectively.

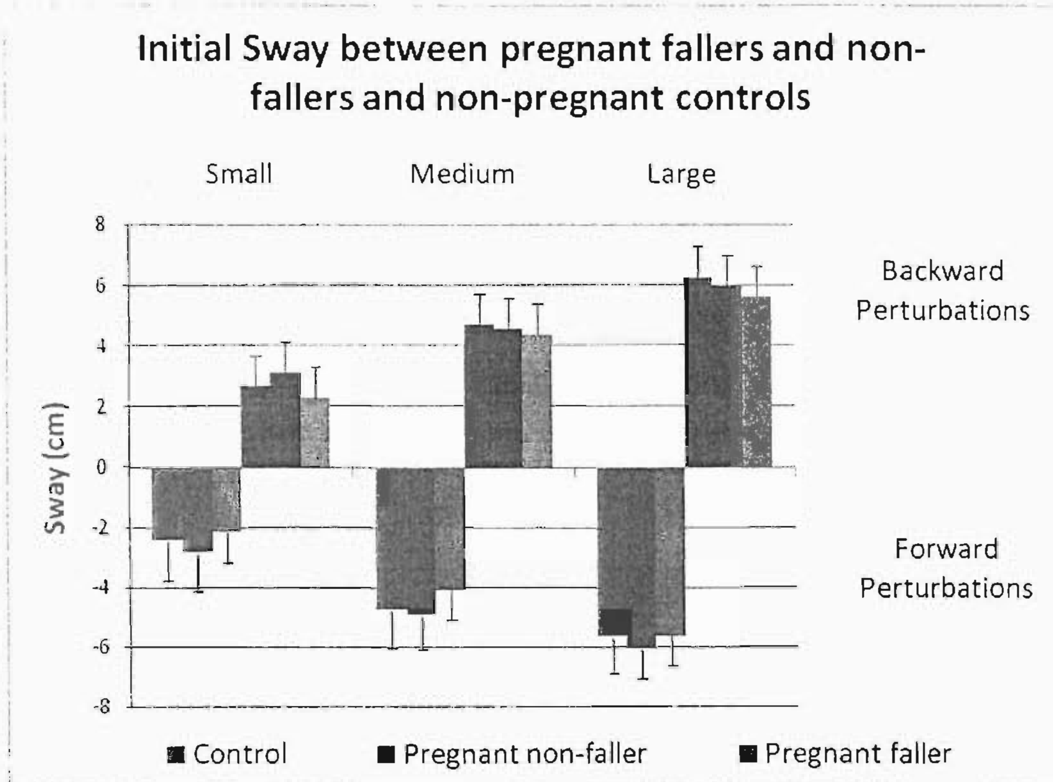


Figure 10: Initial sway between the pregnant fallers, pregnant non-fallers, and non-pregnant controls. The initial sway was significantly different between groups (control, pregnant fallers, and pregnant non-fallers) ($p < 0.001$) and the small, medium, and large perturbations ($p < 0.001$). It was not significantly different between forward and backward perturbations ($p = 0.131$).

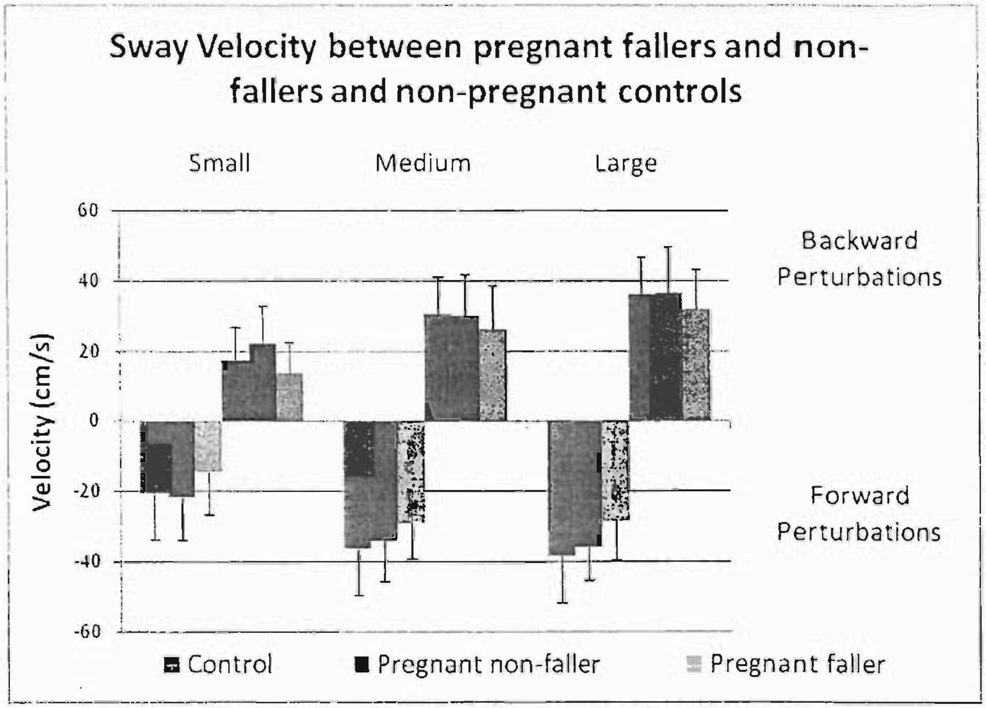


Figure 11: Sway velocity between the pregnant fallers, pregnant non-fallers, and non-pregnant controls. The initial sway was significantly different between groups (control, pregnant fallers, and pregnant non-fallers) ($p < 0.001$), as well as between forward and backward perturbations ($p < 0.001$) and the small, medium, and large perturbations ($p < 0.001$).

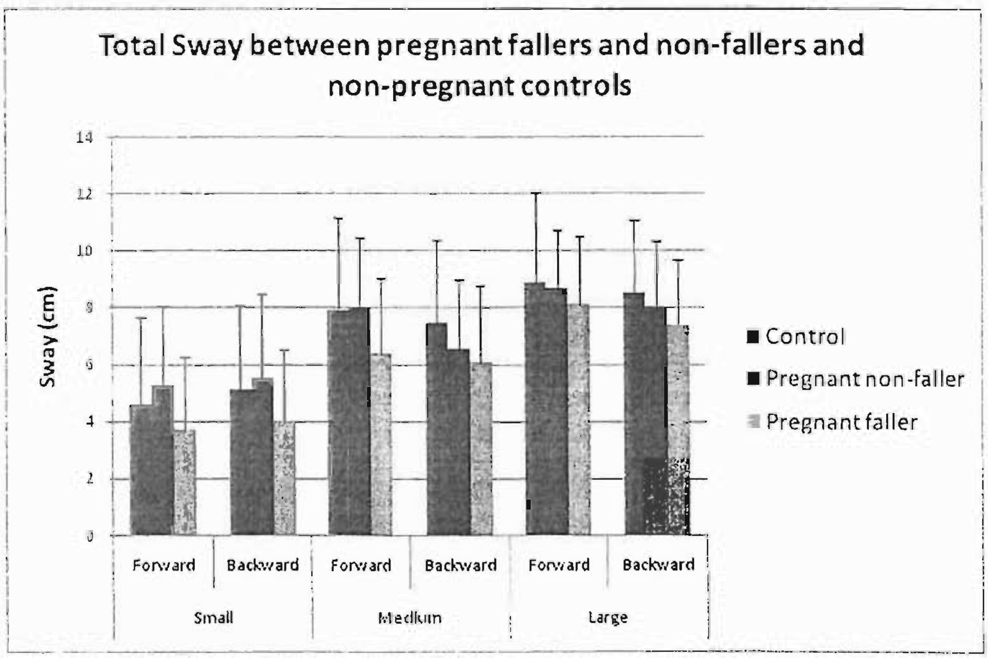


Figure 12: Total sway between the pregnant fallers, pregnant non-fallers, and non-pregnant controls. The sway velocity was significantly different between groups (control, pregnant

fallers, and pregnant non-fallers) ($p < 0.001$), as well as between forward and backward perturbations ($p = 0.027$) and the small, medium, and large perturbations ($p < 0.001$).

We hypothesized that the magnitude of the initial sway, sway velocity, and total COP sway in response to the perturbation would be greater in the pregnant fallers compared to the non-fallers and the non-pregnant control group; however, the opposite was seen such that the pregnant fallers demonstrated less sway and slower sway velocity.

To our knowledge, this is the first study to assess dynamic postural stability in response to a sliding perturbation in pregnant fallers and non-fallers. The pregnant fallers demonstrated increased rigidity, as evidenced by the lack of sway following the perturbation. We have no data on whether or not a subject had a fear of falling. However, for the purposes of this discussion, we performed a post-hoc test to determine if pregnant-fallers became rigid following the first perturbation. Three trials per condition per magnitude were performed in each direction. We examined the data from each of the three trials in each magnitude in each direction to determine if the pregnant fallers became significantly more rigid following the first perturbation while perhaps the non-pregnant controls and pregnant non-fallers did not demonstrate significant differences between trials.

Indeed, the initial sway in the first trial was significantly greater than in trials 2 and 3 ($p < 0.001$). Trials 2 and 3 were not significantly different ($p = 0.108$). However, this was seen in all groups of subjects, not just the pregnant fallers. The interaction between the group (control, pregnant faller and pregnant non-faller) and trial number did not near significance ($p = 0.405$). Therefore, the reason why the pregnant fallers experience less initial sway is not that they experience the first trial and then they get very rigid in response to the latter two trials because all three groups have greater sway on trial 1 than on trials 2 and 3.

The initial sway, total sway, and sway velocity was significantly less during the 3rd trimester than during the 2nd trimester or when compared to the control subjects. The pregnant fallers exhibited similar movement characteristics to the women in their 8th month of gestation, regardless of the trimester.

Anthropometric factors most likely did not play a role in whether or not the subject fell. There were no differences in pregnant mass, weight gain during pregnancy, or waist circumference between the fallers and the non-fallers ($p > 0.10$), nor was there a significant interaction between the trimester and fall incidence for any of the above variables ($p > 0.80$).

The altered response to the sliding perturbation in the pregnant fallers may be due to factors not assessed in this study, such as muscle strength [68]. The official position of the American College of Obstetricians and Gynecologists is that maximal strength testing, maximal weight lifting, and anything activity that could elicit a dramatic pressor response are contraindicated in pregnant women [69]. It is plausible that the pregnant women who fell were weaker than those who did not. Researchers who study older individuals report that decreased lower extremity extensor and hip abductor strength is a risk-factor for falls in the elderly [70-72]. Chambers and Cham asserted that older adults with a higher incidence of falls may not be able to react with the power required to recover balance in response to a hazardous slip [68].

The rate of falls of the pregnant women in our sample was 56%, more than twice that reported by Dunning et al. [3]. In the study by Dunning and colleagues, 6217 women in the greater Cincinnati area were identified as potential study participants through medical records at the hospital in which they delivered. All of the women, who were no more than 8 weeks postpartum and at least 20 years old, were asked to complete a survey either via the mail, the internet, or over the telephone, about whether or not they had fallen while they were pregnant as well as to provide any details about the fall. The women were also queried about whether or not they were currently employed. A total of 3,997 women responded to the survey. Overall, 26.8% of the women reported falling during their pregnancy [3]. The robustness of the large sample size in the Dunning et al. study gives that investigation strong validity.

However, the study by Dunning and coworkers was performed entirely post-partum. The large number of falls reported in our current study may be due to the fact that our questioning the subjects about falls occurred during their pregnancies, not afterward. At their study visit when the participants were at approximately five months gestation, they were given our falls survey. They were given the survey again at approximately 8 months gestation. Many of the women who fell anecdotally mentioned to us that their fall was so minor that they did not think that they would have remembered it had they not been participating in the study. Additionally, several of the women who reported falling in their first trimester told us that they were interested in participating in our study because they had fallen. This may have biased our study to include a greater number of fallers in our sample.

Jang et al. [43] also assessed the incidence of falls of their pregnant study participants over the course of their pregnancies. Only two of their 15 pregnant subjects (13%) reported falling, and one additional subject reported slipping several times. No injuries were sustained during the falls. We cannot explain why the incidence of falls in our study is so much greater than the 13% reported by Jang et al. [43]. The study by Jang et al. took place at the University of Illinois at Champaign-Urbana while our study took place in Pittsburgh, PA. Both locations experience diverse seasons throughout the year, so we do not believe that the difference in the fall rate is related to the weather. Pittsburgh is quite hilly and central Illinois is very flat, but because none of our subjects reported falling down a hill, we do not believe that the difference is due to the terrain. Rather, the difference in the fall rate simply may be attributable to the relatively small sample size in both studies.

Jang and colleagues also collected falls data of their non-pregnant control group. Seven of the 15 control subjects (47%) reported falling over the course of the 40 week study. We did not collect data on the incidence of falls in our control participants. However, the majority of falls of the control subjects (5 of the 7 falls reported) in the study by Jang et al. were during athletic or sporting activities. Further details were not provided, such as whether these non-pregnant subjects were walking, running, dancing, performing Pilates, etc. As such, we cannot speculate about whether the pregnant women in the current study engaged in the activities in which the control subjects of Jang et al. fell.

Effect of Exercise on Fall Risk

The pregnant women in the study reported participation in a variety of exercise modalities. Thirty-one of the 41 pregnant participants reported regular exercise at some point during their pregnancies, while ten reported no exercise at all while pregnant. Several subjects reported participation in more than one exercise modality. Walking was by far the most common exercise modality, with 29 of the 41 pregnant women stating that they walked at least 3 times a week for at least 30 minutes per session at some point during their pregnancy. Prenatal yoga or Pilates was the second most preferred exercise, with 29.2% of the women reporting that they participated in these activities at some point during their pregnancy. Other forms of exercise included jogging, swimming, cycling, aerobics, dancing, strength training, and martial arts. No subject reported participation in organized sports while pregnant. The number of pregnant subjects participating in each exercise is shown in Figure 13.

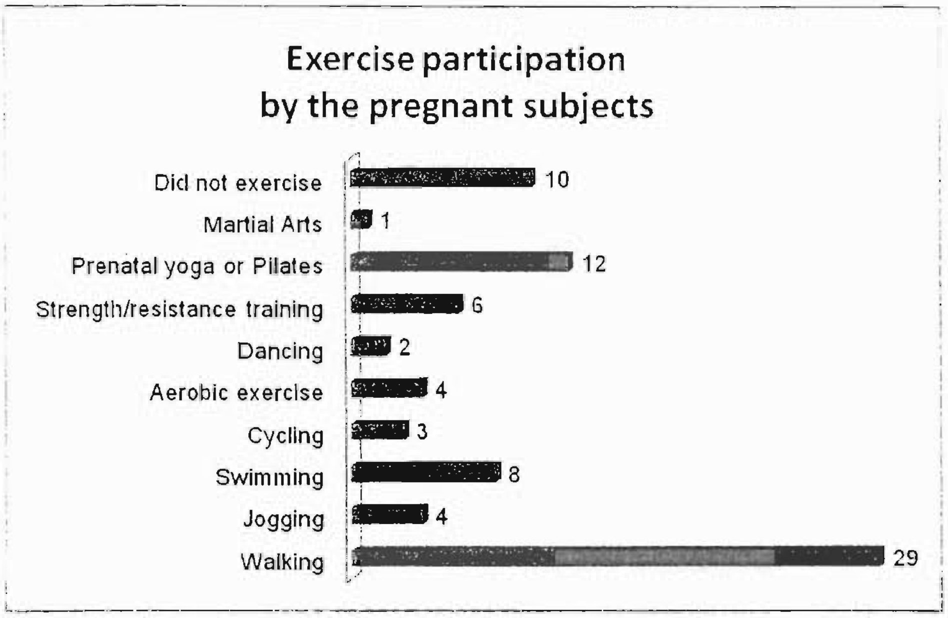


Figure 13: Exercise modalities in which the pregnant subjects reported participating while pregnant.

A Chi-square analysis was performed on the falls and exercise categorization data. Of the 32 women for whom we have complete fall and activity data, 18 were categorized as fallers and 25 were categorized as exercisers. The further distribution of pregnant fallers and non-fallers as well as exercisers vs non-exercisers is shown in Table 7. It is noteworthy that all 7 of the sedentary pregnant women experienced a fall, whereas only 11 of the 25 pregnant women who exercised reported that they fell. Therefore, the faller/exercise categorizations are not independent of one another. The Chi-square for the fall categorization was 0.50 ($p = 0.480$), meaning that fallers were not more statistically likely to be non-exercisers than exercisers. However, the Chi-square for the exercise categorization was 10.125 ($p = 0.001$), meaning that non-exercisers were more likely to fall than those who participated in regular exercise.

Table 7: The categorization 32 pregnant subjects based on whether or not they fell as well as whether or not they exercised. The Chi-square for analysis was 10.125 ($p = 0.001$).

		Exerciser?	
		No	**Yes**
Faller?	**No**	0	14
	Yes	7	11

All of the pregnant subjects in our study completed a survey about their typical daily activities. Qualitative assessment of the activity surveys revealed no apparent differences between the fallers and non-fallers. Therefore, we believe that all of the subjects encountered the same risk factors. A plausible explanation for why some women fell and why some did not would be that the fallers had slower reaction to the factor that precipitated the fall. However, reaction time to the sliding perturbation in this study was not significantly different between the fallers and non-fallers. If we extrapolate this result to the actual fall incident, we do not believe that the fallers would have had a slower reaction time than the non-fallers in response to event which instigated the fall.

We found that that participation in regular exercise at some point during the pregnancy reduces a woman's likelihood of a fall. This finding further supports the hypothesis that increased muscle strength may reduce fall risk. Remarkably, all of the sedentary pregnant women in our study reported a fall. Our sample size of 32 women is relatively small and we certainly cannot extrapolate to assume that all sedentary pregnant women fall. Unfortunately, exercise participation was not addressed in the large study of 3,997 pregnant women by Dunning et al. [3]. Further research on the relationship between exercise participation, exercise modality, and fall risk is warranted.

Effect of employment on falls

Twenty-nine of the 41 pregnant subjects (70.7%) were employed outside of the home. This number is in accordance with the 70% employment rate during pregnancy reported by the Department of Health and Human Services (DHHS) [5]. We assume that all pregnant women encountered the same risk-factors to tripping and slipping in the workplace, home, or in other environments such as the store, yard, etc. In our study, women who were employed were just as likely to fall (50%) as not fall (50%) ($\chi^2 = 0.50$, p=0.480). Six of the 28 falls reported (21.4%) occurred at work. The DHHS reported that 26.6% of employed women fell during their pregnancies with 23.7% of these falls occurring at work [5].

Unemployed women were more likely to fall than not fall. We have complete data sets on eight women who did not work outside the home. Of these, six reported falling and only two did not. Therefore, in our small sample, non-employed women were more likely to fall than not fall ($\chi^2 = 8.00$, p=0.005).

Conclusions

Pregnant women did not demonstrate greater mediolateral motion of the torso during gait. However, a wider base of support was noted during pregnancy. Previous studies on elderly fallers vs non-fallers have purported that individuals with a propensity to fall exhibit greater mediolateral motion of the torso as well as a wider base of support [73, 74]. Our results only partially support these results in pregnant women. Pregnant women demonstrated smaller knee joint moments than the non-pregnant control women, as well as smaller variability in the knee joint moments. This may be indicative of the pregnant women walking with more caution.

Alterations to dynamic stability in response to a sliding postural perturbation emerge in the third trimester of pregnancy. Specifically, while reaction time is not affected by the pregnancy, the amount of COM movement and the velocity of the movement following the perturbation are significantly diminished. Further research is needed to examine the biomechanical and physiological factors behind these findings.

Pregnant women who have experienced a fall exhibit altered dynamic postural stability compared to those who have not fallen as well as non-pregnant women. Namely, while there were no differences in reaction time to a sliding perturbation, the movement of the COP was markedly limited. The pregnant women who have not fallen demonstrated similar COP movement patterns to non-pregnant women. The biomechanical reasons behind this finding need to be further investigated.

Exercise participation may play a role in reducing fall risk. All of the sedentary pregnant women in this study experienced a fall during their pregnancies. While some of the pregnant women who reported exercise participation experienced a fall, the majority did not. Further investigation of the efficacy of exercise in fall prevention in this population is warranted.

Publications

Manuscripts:

McCrory JL, Chambers AJ, Daftary A, Redfern MS. Dynamic postural stability during advancing pregnancy. Journal of Biomechanics (In Review)

McCrory JL, Chambers AJ, Daftary A, Redfern MS. Dynamic postural stability in pregnant fallers and non-fallers. Journal of Biomechanics (In Review)

McCrory JL, Chambers AJ, Daftary A, Redfern MS. Lower extremity kinematics of level walking and stair locomotion during pregnancy. Gait and Posture (In preparation).

McCrory JL, Chambers AJ, Daftary A, Redfern MS. Joint kinetics during level walking and stair locomotion during pregnancy. Gait and Posture (In preparation).

Enders LA, Berger KA, Chambers AJ, Daftary A, Redfern MS, McCrory JL. Alterations in the movement of the center of mass during pregnancy. Clinical Biomechanics (In preparation).

McCrory JL, Chambers AJ, Daftary A, Redfern MS. Alterations of the center of mass movement during pregnancy Clinical Biomechanics (In preparation).

McCrory JL, Enders LA, Berger KA, Chambers AJ, Daftary A, Redfern MS. Toe clearance during stair ascent during advancing pregnancy. Gait and Posture (In preparation).

Professional Presentations:

McCrory JL, Chambers AJ, Daftary A, Redfern MS. Dynamic postural stability in pregnant fallers, non-fallers, and non-pregnant controls. Submitted to: *2009 Annual meeting of the American Society of Biomechanics, University Park, PA August 26-29, 2009.*

Enders LA, Berger KA, Chambers AJ, Daftary A, Redfern MS, McCrory JL. Alterations in the movement of the center of mass during pregnancy. Submitted to: *2009 meeting of the Bio-Medical Engineering Society, Pittsburgh, PA October 7-10, 2009.*

Inclusion of gender and minority study subjects

Form PHS-2590 is attached to this report.

Inclusion of children

Eight women between the ages of 18 and 21 participated in this study. Specifically, two 18 year olds, four 19 year olds, and two 20 year olds participated. This included two pregnant women and six non-pregnant controls recruited from the population of the University of Pittsburgh because they matched the BMI of one of the pregnant women. They were treated exactly the same as all of the other subjects.

Materials available for other investigators
N/A

Final Financial Status Report Form
This will be sent under separate cover from the University of Pittsburgh Office of Research

Final Invention Statement and Certification Form
This form is attached to this message.

<u>Bibliography for the Scientific Report</u>

1. Hall, S., *Chapter 1: What is biomechanics*, in *Basic Biomechanics*. 2006, McGraw-Hall Publishers: Boston. p. 1-28.
2. Winter, D., *Biomechanics and Motor Control of Human Movement*. 3rd ed. 2005, Hoboken, NJ: John Wiley & Sons, Inc. 325.
3. Dunning, K., et al., *Falls in workers during pregnancy: risk factors, job hazards, and high risk occupations*. American Journal of Industrial Medicine, 2003. **44**: p. 664-672.
4. Davey, D., *Normal pregnancy: anatomy, endocrinology, and physiology.*, in *Dewhurst's Textbook of Obstetrics and Gynaecology for Postgraduates, 5th ed.*, C. Whitfield, Editor. 1995, Blackwell Scientific Publications: Oxford. p. 87-108.
5. DHHS, *Vital and Health Statistics. Women: Work and Health*, in *CDC Series 3 (No. 31)*. 1997, Center for Disease Control and Prevention: Hyattsville, MD.
6. NIOSH, *DHHS (NIOSH) Publication Number 2003- 148. National Occupational Research Agenda: Update 2003*. 2003, Centers for Disease Control: Washington, DC.
7. USBLS, *Lost-worktime injuries and illnesses: characteristics and resulting days away from work, 2002*. 2004, US Department of Labor: Washington, DC. p. 1-23.
8. Connolly, A.M., et al., *Trauma and pregnancy*. American Journal of Perinatology, 1997. **14**(6): p. 331-336.
9. Dyer, I. and D. Barclay, *Accidental trauma complicating pregnancy and delivery*. Am J Ob Gyn, 1962. **XX**: p. 907-929.
10. Greenblatt, J., A. Dannenberg, and C. Johnson, *Incidence of hospitalized injuries amount pregnant women in Maryland, 1979-1990*. Am J Prev Med, 1997. **13**(5): p. 374-379.
11. Johnson, J. and L. Oakley, *Managing minor trauma during pregnancy*. J Obstet Gynecol Neonatal Nurs, 1991. **20**(5): p. 379-384.
12. Neufeld, J., et al., *Trauma in pregnancy*. Emerg Med Clin North Am, 1987. **5**(3): p. 623-640.

13. Rothenberger, D., et al., *Blunt maternal trauma: A review of 103 cases.* J Trauma, 1978. **18**(3): p. 173-179.
14. Weiss, H.B., T.J. Songer, and A. Fabio, *Fetal deaths related to maternal injury.* JAMA, 2001. **286**(15): p. 1863-1868.
15. Crosby, W., *Traumatic injuries during pregnancy.* Am J Perinatology, 1983. **14**(6): p. 331-336.
16. Curet, M., et al., *Predictors of outcome intrauma during pregnancy: identification of patients who can be monitored for less than 6 hours.* J Trauma, 2000. **49**(1): p. 18-24.
17. Fildes, J., et al., *Trauma: the leading cause of maternal death.* J Trauma, 1992. **32**(5): p. 643-645.
18. Pearlman, M., J. Tintinalli, and R. Lorenz, *A prospective controlled study of outcome after trauma during pregnancy.* Am J Ob Gyn, 1990. **6**(162): p. 1502-1507.
19. Pearlman, M., J. Tintinalli, and R. Lorenz, *Blunt trauma during pregnancy.* NEFM, 1990. **323**(23): p. 1609-1613.
20. Weiss, H.B., *Pregnancy-associated injury hospitalizations in Pennsylvania, 1995.* Annals of Emergency Medicine, 1999. **34**(5): p. 626-636.
21. Kemmlert, K. and L. Lundholm, *Slips, trips, and falls in different work groups with reference to age.* Saftey Sci, 1998. **28**(1): p. 59-75.
22. Ellis, M., B. Seedhom, and V. Wright, *Forces in women 36 week pregnant and four weeks after delivery.* Engineering Med, 1985. **14**(2): p. 95-99.
23. McNitt-Gray, J., *Biomechanics related to exercise in pregnancy*, in *Exercise in pregnancy, 2nd edition.* 1991, Williams & Wilkins: Baltimore. p. 133-140.
24. Chesley, L., *Weight changes and water balance in normal and toxic pregnancy.* Am J Ob Gyn, 1944. **48**: p. 565-593.
25. Tipton, C., A. Vailas, and R. Matthes, *Experimental studies on the influences of physical activity on ligaments, tendons, and joints: A brief review.* Acta Med Scand, 1986. **Suppl 711**: p. 157-168.
26. Block, R., et al., *Physiological changes in the foot in pregnancy.* J Am Podiatr Med Assoc, 1985. **75**: p. 297-299.
27. Calganeri, M., H. Bird, and W. V, *Changes in joint laxity occurring during pregnancy.* Ann Rheum Dis, 1982. **41**: p. 126-128.
28. Taylor, D.C., et al., *Viscoelastic properties of muscle-tendon units: The biomechanical effects of stretching.* The American Journal of Sports Medicine, 1990. **18**(3): p. 300-309.
29. Miller, D. and R. Nelson, *Biomechanics of sport.* 1973, Philadelphia, PA: Lea & Febiger.
30. Fast, A., et al., *Low back pain in pregnancy. Abdominal muscles, sit-up performance, and back pain.* Spine, 1990. **15**: p. 28-30.
31. Gilleard, W. and J. Brown, *Structure and function of the abdominal muscles in primigravid subjects during pregnancy and the immediate postbirth period.* Phys Ther, 1996. **76**: p. 750-762.
32. Bullock, J., G. Jull, and M. Bullock, *The relationship of low back pain to postural changes during pregnancy.* Aust J Physiother, 1987. **33**: p. 10-17.
33. Franklin, M. and T. Conner-Kerr, *An analysis of posture and back pain in the first and third trimesters of pregnancy.* J Orthop Sports Phys Ther, 1998. **28**: p. 133-138.
34. Dumas, G., et al., *Exercise, posture, and back pain during pregnancy.* Clinical Biomechanics, 1995. **10**: p. 98-103.

35. Snijders, C., et al. *Change in form of the spine as a consequency of pregnancy*. in *11th International Conference on Medical and Biological Engineering*. 1976. Ottawa, ONT, CAN.
36. Foti, T., J.R. Davids, and A. Bagley, *A biomechanical analysis of gait during pregnancy.* Journal of Bone & Joint Surgery - American Volume, 2000. **82-A**(5): p. 625-632.
37. Parsons, C. and S. Redman, *Self-reported cognitive change during pregnancy.* Aust J Adv Nurs, 1991. **9**(1): p. 20-9.
38. Brett, M. and S. Baxendale, *Motherhood and memory: a review.* Psychoneuroendocrinology, 2001. **26**(4): p. 339-62.
39. de Groot, R.H., J.J. Adam, and G. Hornstra, *Selective attention deficits during human pregnancy.* Neurosci Lett, 2003. **340**(1): p. 21-4.
40. Wu, W., et al., *Gait coordination in pregnancy: transverse pelvic and thoracic rotations and their relative phase.* Clinical Biomechanics, 2004.
41. Butler, E.E., et al., *Postural equilibrium during pregnancy: decreased stability with an increased reliance on visual cues.* Am J Obstet Gynecol, 2006. **195**(4): p. 1104-8.
42. Davies, J., et al., *Postural stability following ambulatory regional analgesia for labor.* Anesthesiology, 2002. **97**(6): p. 1576-81.
43. Jang, J., K.T. Hsiao, and E.T. Hsiao-Wecksler, *Balance (perceived and actual) and preferred stance width during pregnancy.* Clin Biomech (Bristol, Avon), 2008. **23**(4): p. 468-76.
44. Maki, B., P. Holliday, and G. Fernie, *Aging and postural control. A comparison and spontaneous and induced sway balance tests.* J Am Gertiatric Soc, 1990. **38**(1): p. 1-9.
45. Redfern, M.S., et al., *Attentional dynamics in postural control during perturbations in young and older adults.* J Gerontol A Biol Sci Med Sci, 2002. **57**(8): p. B298-303.
46. Wooley, S., *An assessment of falls in elderly men and women.* J Gerontology A Biol Sci Med Sci, 1997. **52**(2): p. M80-87.
47. Prudham, D. and J. Evans, *Factors associated with falls inthe elderly: a community study.* Age and Ageing, 1981. **10**: p. 141-146.
48. Owings, T.M. and M.D. Grabiner, *Step width variability, but not step length variability or step time variability, discriminates gait of healthy young and older adults during treadmill locomotion.* J Biomech, 2004. **37**(6): p. 935-8.
49. Maki, B., *Gait changes in older adults: predictors of falls or indicators of fear.* J Am Gertiatric Soc, 1997. **45**(3): p. 313-320.
50. Menz, H.B., S.R. Lord, and R.C. Fitzpatrick, *Acceleration patterns of the head and pelvis when walking are associated with risk of falling in community-dwelling older people.* J Gerontol A Biol Sci Med Sci, 2003. **58**(5): p. M446-52.
51. Hahn, M.E. and L.S. Chou, *Can motion of individual body segments identify dynamic instability in the elderly?* Clin Biomech (Bristol, Avon), 2003. **18**(8): p. 737-44.
52. Chou, L.S., et al., *Medio-lateral motion of the center of mass during obstacle crossing distinguishes elderly individuals with imbalance.* Gait and Posture, 2003. **18**(3): p. 125-133.
53. MacKinnon, C. and D. Winter, *Control of who body balance in the frontal plane during human walking.* Journal of Biomechanics, 1993. **26**: p. 633-644.
54. Simoneau, G.G., et al., *The influence of visual factors on fall-related kinematic variables during stair descent by older women.* Journal of Gerontology, 1991. **46**(6): p. M188-195.

55. Svanstrom, L., *Falls on stairs: an epidemiological accident study.* Scand J Soc Med, 1972. **2**: p. 113-120.
56. Redfern, M.S., et al., *Biomechanics of slips.* Ergonomics, 2001. **44**(13): p. 1138-66.
57. Reuben, D. and A. Siu, *An objective measure of physical function of elderly outpatients. The physical performance test.* J Am Gertiatric Soc, 1990. **38**: p. 1105-1112.
58. Startzell, J.K., et al., *Stair negotiation in older people: a review.* Journal of the American geriatrics Society, 2000. **48**(5): p. 567-80.
59. Startzell, J.K., *Foot clearance and placement during stair descent: The effect of speed and illuminance*, in *Department of Bioengineering.* 1998, The Pennsylvania State University: University Park, PA.
60. Riener, R., M. Rabuffetti, and C. Frigo, *Stair ascent and descent at different inclinations.* Gait & Posture, 2002. **15**: p. 32-44.
61. Costigan, P.A., K.J. Deluzio, and U.P. Wyss, *Knee and hip kinetics during normal stair climbing.* Gait and Posture, 2002. **16**(1): p. 31-37.
62. Brown, L., A. Shemway-Cook, and M. Woollacott, *Attentional demands and postural recovery: the effects of aging.* J Gerontol A Biol Sci Med Sci, 1999. **54A**: p. M165-M171.
63. Shumway-Cook, A., et al., *The effects of two types of cognitive tasks on postural stability in older adults with and without a history of falls.* J Gerontol A Biol Sci Med Sci, 1997. **52A**: p. M232-M240.
64. Pavol, M.J., T.M. Owings, and M.D. Grabiner, *Body segment inertial parameter estimation for the general population of older adults.* J Biomech, 2002. **35**(5): p. 707-12.
65. Winter, D., *Biomechanics and Motor Control of Human Movement, 2nd edition.* 1990, New York: John Wiley and Sons, Inc.
66. Vaughan, C., *Biomechanics of sport*, ed. C. Vaughan. 1989, Boca Raton, Fla: CRC Press.
67. Abdel-Aziz, Y.I. and H.M. Karara. *Direct linear transformation from comparator coordinates into object space coordinates in close-range photogrammetry.* in *ASP Symposium of Close-range photogrammetry.* 1971. University of Illinois, Champaign, IL.
68. Chambers, A. and R. Cham, *Slip-related muscle activation patterns in the stance leg during walking.* Gait and Posture, 2007. **25**: p. 565-572.
69. *ACOG committee opinion. Exercise during pregnancy and the postpartum period. Number 267, January 2002. American College of Obstetricians and Gynecologists.* Int J Gynaecol Obstet, 2002. **77**(1): p. 79-81.
70. Cao, Z.B., et al., *The effect of a 12-week combined exercise intervention program on physical performance and gait kinematics in community-dwelling elderly women.* J Physiol Anthropol, 2007. **26**(3): p. 325-32.
71. Sherrington, C. and S.R. Lord, *Increased prevalence of fall risk factors in older people following hip fracture.* Gerontology, 1998. **44**(6): p. 340-4.
72. Grisso, J.A., *Prevention of falls in patients with osteoporosis.* J Clin Rheumatol, 1997. **3**(2 Suppl): p. 62-4.
73. Cham, R. and M.S. Redfern, *Lower extremity corrective reactions to slip events.* J Biomech, 2001. **34**(11): p. 1439-45.
74. Cham, R. and M.S. Redfern, *Changes in gait when anticipating slippery floors.* Gait Posture, 2002. **15**(2): p. 159-71.

Appendix A: Subject Screening Questionnaire

Pre-Data Collection Safety Precaution Checklist
Biomechanical Stability of Pregnant Women

Subject Number: __________
Visit Number (please circle): 1 (2^{nd} month) 2 (5^{th} month) 3 (8^{th} month)

Subject is ineligible if they answer "Yes" to any of the following:

1) Has your doctor told you that you have toxemia?	Yes	No
2) Are you carrying more than one baby in your uterus?	Yes	No
3) Do you have high blood pressure related to your pregnancy?	Yes	No
4) Do you have any bleeding from your vagina?	Yes	No
5) Have you had a gush of fluid from your vagina?	Yes	No
6) Have you had a sudden swelling of your ankles, hands, or face?	Yes	No
7) Have you had a persistent, severe headache?	Yes	No
8) Have you had a sudden onset of unclear vision?	Yes	No
9) Have you had an unexplained dizzy spell?	Yes	No
10) Have you had swelling, pain, and redness in either of your calves?	Yes	No
11) Have you experienced excessive fatigue?	Yes	No
12) Have you felt heart palpitations and/or chest pain?	Yes	No
13) Have you had any persistent contractions (>6-8 per hour that may suggest onset of premature labor?	Yes	No
14) Have you had any other unexplained abdominal pain?	Yes	No

The PI will then take the subject's blood pressure and pulse.
Pulse: _________ bpm
Blood Pressure: ________ / ________

Testing will not be performed if the pulse exceeds 100 or the blood pressure exceeds 150/90

Appendix B: Subject Activity Form

Subject Questionnaire

Biomechanical Stability of Pregnant Women

General:

1. Age: ___________
2. Medications:

____

____

____

3. Does someone help you with tasks around the house? **Yes** **No**
4. Do you wear glasses or contacts? **Yes** **No**
5. Have you had previous problems with balance or vision prior to your pregnancy? **Yes** **No**
   a. If yes, what problems? ______________________________
6. Are there stairs in your home? **Yes** **No**
   a. If yes, how often do you climb them? _________ times/day
7. What type of shoes do you normally wear? (i.e. sneakers, heels, boots)

____

Prior Pregnancies:

8. Have you been pregnant previously? **Yes** **No**
   a. How many times? __________
   b. How many resulted in live births? __________
   c. What are the ages of your children? ______________________

Exercise Habits:

9. Do you currently exercise? **Yes** **No**
   a. How often? _______ times/week
   b. Duration of exercise session: _________
   c. What type of exercise?

Circle all that apply:

Organized Sports	Walking	Jogging/Running	Swimming	Bicycling	Skating
Martial Arts	Tai Chi	Aerobics	Dancing	Strenght/Weight Training	Yoga

Other – please describe: ______________________________

10. Was this exercise regimen started before pregnancy? **Yes** **No**

Work:

11. Are you currently employed? **Yes** **No**
12. In what type of business do you work? ________________________________
13. Do you work full-time or part-time? Full Part
14. What time of day do you usually work? ________________________________
15. Do you often work overtime? **Yes** **No**
    a. If yes, how many hours of overtime do you usually work per week? __________
16. Do you work a rotating shift? **Yes** **No**
17. How many breaks do you have per shift? ___________
    a. What is the duration of each break? ___________
18. Do you perform lifting tasks at work? **Yes** **No**
    a. If yes, approximately how much weight is lifted? _________
    b. How often? _________ time/day
19. Has your employer made any accommodations for you during your pregnancy?
    Yes **No**
    a. If yes, what accommodations have been made?
    ____
20. Do you feel your job is stressful? **Yes** **No**

Falls:

21. Did you experience any loss of balance resulting in a fall where some part of your body – other than your feet – touched the ground?

    During **this pregnancy**: **Yes** **No**

    During **previous pregnancies**: **Yes** **No**

    In the **past year**: **Yes** **No**

    If any of the answers on Question 21 are yes, please fill out **Fall Incident Information Form**

Appendix C: Fall Incident Information Form

Fall Incident Information Form

Please fill this form out as accurately as possible

Fall Description:

1. Date and time of fall: ______________________________
2. Month of gestation at time of fall: __________
3. Location of fall (i.e. home, work, etc.): ______________________________
4. What were you doing at the time of the fall? (Circle one)
    a. Carrying an object or child
    b. Turning, reaching, or bending
    c. Pushing, pulling, or lifting
    d. Hurried pace
    e. Running
    f. Other – please describe: ______________________________
5. Did you fall from an elevation greater than 3 feet? **Yes No**
6. What shoes were you wearing at the time of the fall (sneakers, heels, boots, etc.)?

    ____
7. Were you ill at the time of the fall (i.e. hypoglycemia, nausea, vomiting, diarrhea)? **Yes No**
8. Were you performing a new task or unfamiliar task at the time of the fall?
9. If the fall occurred at work, was the fall reported to your employer? **Yes No**
    a. Was a workers' compensation claim filed as a result of the fall? **Yes No**

Injury:

10. Did you sustain an injury as a result of the fall? **Yes No**
    a. If yes, what injury did you sustain as a result of the fall?

    ____
11. Did the fall result in a visit to your physician? **Yes No**
12. Did the fall result in a visit to the Emergency Room? **Yes No**
13. Did the fall result in a hospital admission? **Yes No**
    a. If yes, how many days were you in the hospital? __________
14. Did the fall result in restricted activity? **Yes No**
    a. If yes, how many days were restricted? __________
15. Did the fall result in missed days of work? **Yes No**
    a. If yes, how many days of work were missed? __________

Appendix D: Anthropometric data collection form

Biomechanical Stability of Pregnant Women
Anthropometry Sheet

Subject Number: ________ Visit: ________

Group (Preg or Con): ________ Age: ________

Weeks Pregnant: _____
Pre-pregnancy weight: _______ (as reported by the subject).

Use the medical scale and stadiometer for these measurements:

Site	Measurement
Body Mass (kg)	
Body Height (cm)	

Use the cloth tape measure for these circumferential measurements:

Site	Measurement (cm)
Head Circumference	
Neck Circumference	
Waist Circumference	
Hip Level Torso Circumference	
Mid-thigh Circumference	
Leg Maximum Circumference	

Use the small anthropometer with the curved arms for these measurements:

Site	Measurement (cm)
Head Width	
Head Depth	
Elbow Width	
Wrist Width	
Knee Width	
Ankle Width	

Use the tape measure taped behind the lab door for these height measurements:

Site	Measurement (cm)
*C7 Height	
*Acromion Height	
Shoulder Height	
Breast Height	
*L3L4 Height	
Hip Height	

Use the large anthropometer with the straight arms for these measurements:

Site	Measurement (cm)
Ulnar Styliod to Lateral Epi. of Humerus	
Lateral Epi. of Humerus to Acromion	
Shoulder to Shoulder Width	
Shoulder Level Trunk Depth	
Breast Level Trunk Width	
Breast Level Trunk Depth	
Axis Depth at Breast	
Mid-breast L3L4 Trunk Width	
Mid-breast L3L4 Trunk Depth	
Axis Depth at Mid-breast L3L4	
L3L4 Level Trunk Width	
L3L4 Level Trunk Depth	
Axis Depth at L3L4	
Thigh Length (hip to tibial plateau)	
*Shank Length	
Foot Length	
*Lateral Malleous Height	
Leg Length (ASIS to med malleolus)	
Inter ASIS distance	

Use the goniometer with the small blue level for this measurement:

Site	Measurement (deg)
Hip to shoulder angle	

Program Director/Principal Investigator (Last, First, Middle): McCrory, Jean L.

Inclusion Enrollment Report

This report format should NOT be used for data collection from study participants.

Study Title: Biomechanical Stability of Pregnant Women

Total Enrollment: 85 **Protocol Number:** 0505095

Grant Number: OH 0008548

PART A. TOTAL ENROLLMENT REPORT: Number of Subjects Enrolled to Date (Cumulative) by Ethnicity and Race

Ethnic Category	Sex/Gender: Females	Males	Unknown or Not Reported	Total
Hispanic or Latino	3	0	0	3 **
Not Hispanic or Latino	82	0	0	82
Unknown (individuals not reporting ethnicity)	0	0	0	0
Ethnic Category: Total of All Subjects*	85	0	0	85 *
Racial Categories				
American Indian/Alaska Native	1	0	0	1
Asian	5	0	0	5
Native Hawaiian or Other Pacific Islander	0	0	0	0
Black or African American	6	0	0	6
White	72	0	0	72
More Than One Race	1	0	0	1
Unknown or Not Reported	0	0	0	0
Racial Categories: Total of All Subjects*	85	0	0	85 *

PART B. HISPANIC ENROLLMENT REPORT: Number of Hispanics or Latinos Enrolled to Date (Cumulative)

Racial Categories	Females	Males	Unknown or Not Reported	Total
American Indian or Alaska Native	1	0	0	1
Asian	0	0	0	0
Native Hawaiian or Other Pacific Islander	0	0	0	0
Black or African American	0	0	0	0
White	2	0	0	2
More Than One Race	0	0	0	0
Unknown or Not Reported	0	0	0	0
Racial Categories: Total of Hispanics or Latinos**	3	0	0	3 **

* These totals must agree.
** These totals must agree.

Form Approved Through 11/30/2010
OMB No. 0925-0001

Department of Health and Human Services

Final Invention Statement and Certification

(For Grant or Award)

DHHS Grant or Award No.

OH 008458

A. We hereby certify that, to the best of our knowledge and belief, all inventions are listed below which were conceived and/or first actually reduced to practice during the course of work under the above-referenced DHHS grant or award for the period

07/01/2005 through 12/31/2008.

original effective date — *date of termination*

B. Inventions (Note: If no inventions have been made under the grant or award, insert the word *"NONE"* under Title below.)

NAME OF INVENTOR	TITLE OF INVENTION	DATE REPORTED TO DHHS
Jean L. McCrory	None	
(Use continuation sheet if necessary)		

C. Signature — This block ***must*** be signed by an official authorized to sign on behalf of the institution.

Title Director, Office of Research	Name and Mailing Address of Institution University of Pittsburgh Office of Research 350 Thackeray Hall Pittsburgh, PA 15260
Typed Name Allen A. DiPalma	
Signature Allen A. DiPalma — Date 04/01/09	

HHS 568 (Rev. 11/07)