Clinical Biomechanics 29 (2014) 143–148

Contents lists available at ScienceDirect

Clinical Biomechanics

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

Ground reaction forces during stair locomotion in pregnant fallers and non-fallers☆

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

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

ARTICLE INFO

Article history:
Received 5 April 2013
Accepted 26 November 2013

Keywords:
Stairs
Center of pressure
Ground reaction forces
Pregnancy
Falls

ABSTRACT

Background: More than 27% of pregnant women fall. Approximately 40% of falls occur during staircase locomotion. The purpose of this study was to examine ground reaction forces in pregnant fallers, pregnant non-fallers, and non-pregnant controls to determine if pregnant fallers display alterations to ground reaction forces that increase their risk of falling on stairs.

Methods: Fifteen pregnant fallers and 14 pregnant non-fallers participated during their second and third trimesters. Forty non-pregnant women served as controls. Subjects ascended and descended a four-step staircase. A force plate in the second stair collected ground reaction forces. Ascent and descent velocities were assessed. In the statistics, group (pregnant faller, pregnant non-faller, control) and subject were independent variables. Stance time and ascent/descent velocity were analyzed with an ANOVA. Mediolateral center of pressure excursion was analyzed with an analysis of covariance. Ground reaction forces were categorized into anterioposterior, mediolateral, and vertical forces and normalized to the subject's bodyweight. A multivariate analysis of covariance was used to compare between groups and subjects for each force category, with velocity as the covariate ($\alpha = 0.05$).

Findings: Pregnant fallers had an increased anterioposterior braking impulse ($P < 0.01$), medial impulse ($P = 0.02$), and minimum between vertical peaks ($P = <0.01$) during ascent. During descent, pregnant fallers demonstrated a smaller anterioposterior propulsive peak and propulsive impulse ($P = 0.03$) and a greater minimum between vertical peaks ($P < 0.01$).

Interpretation: These alterations are likely related to a strategy used by pregnant fallers to increase stability during staircase locomotion.

1. Introduction

More than 27% of pregnant women fall, making falls a leading cause of trauma-related hospital admissions in pregnancy (Dunning et al., 2010). Forty-percent of falls occur during stair locomotion, although it is unknown if more happen during ascent or descent (Dunning et al., 2010). Many physiological changes associated with pregnancy may be related to this increased fall risk because they may alter the position of the center of mass (CoM) or decrease dynamic control during gait. These alterations include: increased spinal lordosis (Dumas et al., 1995), increased ligamentous laxity (Calguneri et al., 1982), substantial weight gain (Calguneri et al., 1982; McCrory et al., 2010a), decreased abdominal muscle strength (Gilleard and Brown, 1996), swelling of the extremities (Kent et al., 1999), and decreased neuromuscular coordination (Wu et al., 2004).

Biomechanical alterations associated with pregnancy include a greater step width and increased mediolateral motion of the torso and CoM during gait in the third trimester (Foti et al., 2000; Lymbery and Gilleard, 2005). The greater step width may be an adaptation to increase frontal plane stability in reaction to the increased side-to-side trunk displacement. No significant pregnancy-related differences in ground reaction force (GRF) variables during level walking have been reported (Lymbery and Gilleard, 2005), although walking velocity may slow in pregnancy (McCrory et al., 2011), making it a confounding variable when examining the effect of pregnancy on GRF variables.

Staircase locomotion is reported to be one of the most challenging activities of daily living by community dwelling adults (Verghese et al., 2008). In the general population, falls are more likely to occur during descent (Tinetti et al., 1988). Healthy older individuals without a history of falls display a lower vertical passive peak and anterioposterior push-off peak during ascent and an increased vertical loading rate and anterioposterior braking peak during descent when compared to

☆ Funding sources: NIOSH K01 OH8548.

* Corresponding author at: Division of Exercise Physiology, Department of Human Performance and Applied Exercise Science, West Virginia University, 8315 Health Sciences Center—South, P.O. Box 9227, Morgantown, WV 26506-9227 USA.
E-mail address: jlmccrory@hsc.wvu.edu (J.L. McCrory).

0268-0033/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.clinbiomech.2013.11.020

younger women (Bertucco and Cesari, 2009; Hamel et al., 2005). Older fallers display slower descent velocities and greater peak braking forces than non-fallers (Vanicek et al., 2010). In a previous study, we examined the effect of advancing pregnancy on GRF variables during staircase locomotion. The mediolateral excursion of the center of pressure (CoP) and the anterioposterior braking impulse during ascent increased during pregnancy, particularly in the third trimester (McCrory et al., 2013). The increased mediolateral excursion of the CoP may be indicative of a decrease in dynamic postural control or it may be a reaction to the increased side-to-side movement of the CoM seen during gait. The increased braking impulse may increase fall risk because a greater frictional force would be required to prevent a slip.

Given that pregnant women undergo a number of physiological changes that may decrease dynamic stability and that other populations at an increased risk of falling display changes to their ground reaction forces during staircase locomotion, it is important to study ground reaction forces in pregnant fallers to better understand the reasons behind the increased fall risk on stairs in pregnancy. We have previously reported that the pregnant fallers who participated in the current study displayed biomechanical differences when compared to pregnant non-fallers in other measures such as CoP movement following perturbations to quiet stance and in trunk mechanics during gait. Specifically, pregnant fallers showed less anterioposterior movement of the CoP (McCrory et al., 2010b) and a stiffer ankle (Ersal et al., 2012) in response to an anterioposterior translational perturbation to quiet stance. Additionally, pregnant fallers exhibited less lateral lean of the trunk at heel strike as well as less thorax rotation throughout the stride (McCrory et al., 2012). These previous findings suggest that GRF variables may also differ between pregnant fallers and non-fallers during stair locomotion.

The purpose of this study was to compare GRF variables during stair locomotion in pregnant women who have fallen while pregnant, pregnant women who have not fallen, and non-pregnant women. Based on our previous research, we hypothesized that the mediolateral CoP excursion and the anterioposterior braking impulse would be greater in the pregnant fallers compared to the pregnant non-fallers and controls.

2. Methods

2.1. Subjects

Forty-one pregnant and 40 non-pregnant women between the ages of 18 and 45 participated (Table 1). Control and pregnant participants were matched to within 2 kg/m^2 BMI, based on the pregnant subject's self-reported pre-pregnancy mass. Mass was significantly different between each of the trimesters and the controls ($P < 0.001$); however, it was not different between pregnant fallers and non-fallers ($P = 0.421$). Age and height were not different between groups ($P > 0.05$). Pregnant subjects participated in two visits, each occurring in the middle of their second and third trimesters. Data of control subjects were collected in a single session in the week following menses when estrogen and progesterone concentrations are low (Tortora and Brabowski, 2000), because estrogen and progesterone may influence movement patterns and dexterity (Lebrun, 1994; Posthuma et al., 1987; Yack et al., 2003).

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

Twelve pregnant women withdrew from study participation following their first visit for the following reasons: chose not to participate (n = 4), pregnancy complications (n = 2), subject injured in a fall (n = 1), preterm delivery (n = 4), and relocation away from the area (n = 1). Only data from the 29 pregnant subjects who completed the study are included.

Table 1
Subject demographics: mean (standard deviation).

	Control group (n = 40)	Pregnant group (n = 29)			
		Non-fallers (n = 14)		Fallers (n = 15)	
Age (yrs)	26.5 (6.4)	30.8 (3.7)		29.4 (4.5)	
Height (cm)	165.8 (5.6)	167.4 (7.2)		165.7 (6.4)	
		Second trimester	Third trimester	Second trimester	Third trimester
Weeks pregnant		20.8 (1.3)	35.8 (1.6)	21.1 (1.2)	35.7 (1.4)
Mass	64.7 (8.8)	73.4 (11.2)	82.1 (12.5)	73.3 (8.9)	81.0 (9.6)

Subject mass was significantly different between the control group and each of the trimesters ($P < 0.001$). Subject mass, age, weeks pregnant, and height were not significantly different between pregnant fallers and pregnant non-fallers ($P > 0.05$).

2.2. Procedures

Subjects reported to the Human Movement and Balance Laboratory at the University of Pittsburgh for testing. Experimental procedures were explained to the subject. Following this, written informed consent was obtained.

Pregnant subjects were surveyed about falls during this pregnancy. A fall was defined as a loss of balance such that another part of the body other than a foot touched the ground. Twenty-four falls were reported by 15 of the 29 women in the study (McCrory et al., 2010b). If a subject stated that she fell during this pregnancy, she was categorized as a "pregnant faller". Those who did not fall were categorized as "pregnant non-fallers" (n = 14). Additional results of the falls survey were previously reported (McCrory et al., 2010b).

Height and mass were obtained using a standard medical scale and stadiometer. Subjects wore comfortable clothing and their own athletic shoes. A spherical retroreflective marker was placed on the L3L4 spinal segment for use in determining walking velocity.

Subjects practiced ascending and descending a four-step wooden staircase. The rise, run, and width of each stair were 20.3 cm, 26.8 cm, and 91.4 cm, respectively. A handrail, located on the subject's left side during ascent and right side during descent, was provided. A 91.4 cm by 69.9 cm platform was provided at the top of the staircase to allow subjects to comfortably turn around. Subjects were instructed to lightly touch the handrail only if needed. No force measurements were made on the handrail. Each subject wore a harness for protection in case of a fall. A laboratory assistant operated a belay system to catch the subject should a fall occur. However, no subject fell during testing.

A Bertec force plate (Model 4060A, Bertec Corp, Columbus, OH, USA, 1080 Hz) located in the second stair was used to collect GRF data. The force plate was structurally isolated from the staircase. Movement of the L3L4 marker was captured with a VICON system (VICON, Inc., Denver, CO, USA, 120 Hz); from this, ascent and descent velocities were calculated as the average resultant velocity of the L3L4 marker. Five trials of the right leg during ascent and the left leg during descent were obtained. Rest periods were provided as needed.

GRF data were processed in Matlab (Version R2008a. Mathworks, Inc., Natick, MA, USA). Data were filtered with a fourth order low-pass, phaseless Butterworth filter with a cutoff frequency of 50 Hz. Initial