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Lower Extremity Kinetics and Muscle Activation During Gait Are Significantly Different During and After Pregnancy Compared to Nulliparous Females

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Background: Low back, pelvic, and lower extremity pain are common during and after pregnancy. Understanding differences in mechanics between pregnant and non-pregnant females is a first step toward identifying potential pathological mechanisms. The primary purpose of this study was to compare joint kinetics and muscle activation during gait between females during and after pregnancy to nulliparous females.

Methods: Twenty pregnant females completed testing on three occasions (second trimester, third trimester, and post-partum), while 20 matched, nulliparous controls were tested once. Motion capture, force data, and surface electromyography were averaged across seven trials during gait. Lower extremity kinematics, lower extremity moments and work normalized to pre-pregnancy body mass, work distribution, and peak and average muscle activation amplitude were calculated. Independent t-tests were conducted between pregnant and nulliparous females at each time point.

Results: Compared to controls, peak hip abductor moments were greater throughout pregnancy. Females in second trimester also demonstrated greater sagittal negative ankle work and greater percent contribution of the ankle and smaller percent contribution of the hip to negative work. Compared to controls, during third trimester there were greater knee abductor, ankle plantarflexor, and ankle dorsiflexor moments and greater work at the ankle and total work. Several moment and work variables continued to be elevated post-partum compared to controls. Gluteus maximus muscle activation amplitude was smaller in second trimester and post-partum compared to controls.

Significance: While overall joint demands were greater during and after pregnancy, there was a smaller relative sagittal utilization of the hip early in pregnancy and smaller gluteus maximus muscle amplitude during second trimester and post-partum. Because the gluteus maximus muscle contributes to force closure and dynamic stability of the low back and pelvis, relative gluteus maximus disuse, concurrent with increased joint loads, could potentially contribute to pain during and after pregnancy.

INTRODUCTION

More than 3.9 million females give birth in the United States annually [1]. Concurrent with the anatomical and physiological changes of pregnancy, more than half of pregnant females report hip, knee, or foot pain [2] and another half report pelvic or low-back pain [3-5]. There are long term implications of pregnancy related pain with increased prevalence of lower extremity [2] and pelvic or low back pain [4, 6-9] among post-partum females. Pain in pregnant females is associated with depression [10] and impacts short and long term health and quality of life [11]. Identification of how trunk and lower extremity neuromechanics differ during and after pregnancy is the first step toward understanding factors potentially contributing to pain. Because gait is a critical component of everyday living [12] and pregnant females with pelvic and low back pain often report pain during walking [13], exploration of neuromuscular adaptations during gait in pregnant and post-partum females may inform potential pain mechanisms.

Few studies report joint kinetics in pregnant females [14-18] and most studies utilize body mass normalized moments [14-16, 18]. Due to localized increases in body mass, normalization of kinetics to body mass during pregnancy may result in underestimation of changes occurring at the individual joint level during pregnancy. For example, the joint and tissues around the joint are the same size despite increased total body mass during pregnancy. Foti et al [17] reported non-body mass normalized kinetics and found greater peak moments and power during the third trimester of pregnancy as compared to 1 year post-partum. They also report greater peak hip and ankle moments and power during pregnancy [17], indicating greater demand on the lower extremity joints compared to post-partum. Use of pre-pregnancy body mass for normalization of kinetics throughout pregnancy is a novel solution which could be used to identify changes in demand at the joint level during pregnancy while still using a method of normalization to account for individual differences. Because of the continued increased incidence of orthopedic pain post-partum compared to nulliparous females [4, 6-9] and because it is unknown whether joint kinetics revert to typical levels post-partum, additional insight would also be gained from comparing gait mechanics during and after pregnancy to a nulliparous, control group, rather than using post-partum data to define typical kinetics.

Furthermore, while joint power has been reported in this population [17], lower extremity work, which quantifies joint demand throughout gait rather than at one peak, has not been reported during pregnancy. Joint work may better represent total demand at that joint, which has relevance to joint pathology. Additionally, due to changes in body mass distribution during and after pregnancy [19, 20], determination of the percent contribution of each lower extremity joint to total lower extremity work during gait could be used to quantify the gait strategy utilized to accommodate pregnancy (for example, if increases in work occur to a greater extent at one joint than others). Electromyography (EMG) can provide additional information regarding how muscle groups within an area are activated which may also elucidate musculoskeletal adaptations during and after pregnancy. Few studies have evaluated changes in muscle activation during or after pregnancy [21, 22] and these changes have not been reported during gait. Therefore, the purposes of this study were to compare lower extremity joint loading and muscle activation during over-ground walking between pregnant females followed longitudinally across the second trimester (2T), third trimester (3T), and post-partum with matched, nulliparous females.

2. METHODS

2.1. Participants

Twenty-four pregnant females were recruited. One pregnant participant withdrew due to medical complications, leaving 23 pregnant females who completed 2T testing. Pregnant females were included if they were 19-50 years old and in the first or second trimester at the time of recruitment. Pregnant females were excluded if they had a history of back surgery or contraindications to moderate intensity exercise. Twenty-three nulliparous females, matched to the pregnant participants by age within 3 years and body mass index within 2 kg/m^2 of self-reported pre-pregnancy body mass index [23] were recruited. Nulliparous participants were excluded if they had a history of lower extremity or back surgery, reported complaints of low back or lower extremity pain during the preceding 6-months, or had contraindications to moderate intensity exercise. All participants signed the University IRB approved informed consent form and pregnant partipcants obtained written consent from the treating Obstetrician or mid-wife prior to participation.

2.2. Instrumentation

Three-dimensional lower extremity kinematics and kinetics were collected using an 8-camera motion capture system (Qualisys, Gothenburg, Sweden, 100 Hz sampling rate) and force plates (Bertec, Columbus, OH, USA, 2000 Hz sampling rate), respectively. The lower extremity and pelvis segments were defined by 14 mm opto-reflective markers placed on the distal second toes, first and fifth metatarsal heads, medial and lateral malleoli, medial and lateral femoral epicondyles, greater trochanters, anterior superior iliac spines, iliac crests, L5-S1 junction, and acromioclavicular joints. Tracking markers included the iliac crest, L5-S1, and acromioclavicular markers as well as semi-rigid clusters on the thighs, shanks, and heels. The pelvis was tracked by the iliac crest and L5-S1 markers [24] which allowed for accurate tracking of the pelvis even as the abdomen increased in size. The trunk was defined and tracked by the acromion and iliac crest markers. A 5 second static calibration file was collected with all markers, following which non-tracking markers were removed.

Disposable silver/silver-chloride bipolar surface EMG electrodes were placed bilaterally on the lumbar erector spinae, gluteus medius, and gluteus maximus muscles according to standard recommendations [25]. These muscles were selected due to the potential to provide insight regarding changes in activation that may influence low back or pelvic girdle pain [26]. EMG data were sampled at 2000 Hz using a wireless 16 Channel EMG System (Delsys Trigno, Natick, MA, USA).

2.3. Procedures

In this longitudinal, case-control study, pregnant participants completed testing during 2T (21.0 $\pm$ 3.5 weeks pregnant), 3T (33.0 $\pm$ 2.2 weeks pregnant), and 4-6 months post-partum (20.5 $\pm$ 2.2 weeks) for a total of three testing sessions for each pregnant participant. Matched, nulliparous females (controls) completed testing once. Participants completed seven successful gait trials [27] at a self-selected velocity across a 16-meter walkway. A trial was successful if the foot of the dominant limb landed completely within the dimensions of the force plate. Gait velocity was monitored via photoelectric triggers to ensure that velocity remained within 10% of the mean of the first three trials. All datasets were collected, integrated and synchronized by Qualisys Track Manager (QTM; Qualisys, Gothenburg, Sweden) and tabulated for further analysis.

2.4. Data Analysis

Kinematic and ground reaction force data were low-pass filtered at 6 Hz and 20 Hz, respectively, using a 4th-order Butterworth filter with Visual 3D software, Version 4 (C-motion Inc., Rockville, MD, USA). A cardan sequence of mediolateral (X), anteroposterior (Y), and vertical (Z) was used. Mean kinematics and kinetics for each subject were averaged across the seven trials for the dominant limb. Peak trunk relative to the pelvis, pelvis relative to the lab coordinate system, hip, knee, and ankle kinematics and peak hip, knee, and ankle internal moments were calculated.

Mean sagittal plane positive and negative work across the seven trials were calculated for the hip, knee, and ankle using a custom-written code in Matlab, Version 9.5 (MathWorks Inc., Natick, MA, USA) to determine the area under the positive and negative portions of the power curve. Total sagittal plane power was calculated by summing the absolute values of the positive and negative work at each joint. Positive, negative, and total sagittal plane lower extremity mechanical work were calculated by summing positive, negative, and total work across the hip, knee, and ankle, respectively. Percent contribution of the hip, knee, and ankle to positive, negative, and total lower extremity work were calculated by dividing the positive, negative, and total work of the hip, knee, and ankle by the positive, negative, and total work for the lower extremity, respectively, and multiplying by 100.

EMG data were bandpass filtered at 10 to 450 Hz and notch filtered at 60 Hz. Data were full-wave rectified and low-pass filtered at 6 Hz to create a linear envelope [28]. Data were amplitude normalized with respect to the peak value obtained for each muscle across the entire gait cycle of the seven trials [29]. Peak and average muscle activation were calculated for the ipsilateral limb for stance phase of gait using a custom-written code in Matlab.

2.5. Statistical Analysis

The primary variables of interest were sagittal plane and abductor hip and knee, and sagittal plane ankle moments; sagittal plane positive, negative, and total mechanical lower extremity work and percent contribution to lower extremity work of the hip, knee, and ankle; and peak and average percent amplitude of the ipsilateral erector spinae, gluteus medius, and gluteus maximus muscles during stance phase of gait. As a secondary analysis, peak sagittal, frontal, and transverse plane trunk, pelvis, and hip, sagittal and frontal plane knee, and sagittal plane ankle kinematics were calculated to help inform the interpretation of the joint kinetics. Independent t-tests between pregnant and control females at all three-time points were conducted to assess group differences in the variables of interest. Statistics were analyzed using SPSS software, Version 25 (SPSS, Inc., Chicago, IL) with an alpha value of 0.05. Cohen's d effect sizes were also calculated for statistically significant findings.

3. RESULTS

3.1. Subject Demographics and Gait Velocity

Of the 23 pregnant females who completed 2T testing, one participant declined to participate during 3T due to low back pain and two participants were lost to follow-up post-partum. Therefore, 20 pregnant females completed all three testing sessions and were included with their 20 matched, controls in analyses. There were no significant differences between pregnant participants and controls with respect to age, height, or baseline body mass (pregnant participants self-reported body mass prior to this pregnancy). As expected, mass was greater in 2T and 3T than controls ($p=0.011$ and $p<0.001$). There were no significant differences in gait velocity between pregnant females and controls at any time point ($p>0.05$) (Table 1).

3.2. Moments, Work and Percent Contribution of Lower Extremity Joints to Work

Pregnant females in 2T, compared to controls, demonstrated greater internal peak hip abductor moments ($p=0.026$; $d=0.73$). Pregnant females in 3T, compared to controls, demonstrated greater peak moments for hip abductors ($p<0.001$; $d=1.30$), knee abductors ($p=0.009$; $d=0.87$), ankle dorsiflexors ($p=0.021$; $d=0.76$), and ankle plantarflexors ($p<0.001$; $d=1.33$). Post-partum females, compared to controls, continued to demonstrate greater peak moments for hip abductors (p=0.019; d=0.77), knee abductors (p=0.016; d=0.89), and ankle dorsiflexors (p=0.017; d=0.80) (Table 2).

Pregnant females in 2T, compared to controls, demonstrated greater sagittal negative ankle work (p=0.023; d=0.75). Pregnant females in 3T, compared to controls, demonstrated greater sagittal negative ankle work (p=0.006; d=0.93), total ankle work (p=0.002; d=1.06), and positive (p=0.013; d=0.82) and total (p=0.023; d=0.75) lower extremity work. Post-partum females, compared to controls, demonstrated greater sagittal positive knee work (p=0.001; d=1.19), and positive (p= 0.001; d=1.17) and total (p=0.041; d=0.67) lower extremity work (Figure 1).

Pregnant females in 2T, compared to controls, demonstrated smaller percent contribution of the hip to sagittal negative work (p=0.033; d=0.67) and greater percent contribution of the ankle to sagittal negative work (p=0.042; d=0.70). Relative contribution of each lower extremity joint to sagittal work did not differ between pregnant females in 3T and controls (p>0.05). Post-partum females, compared to controls, demonstrated a greater percent contribution of the knee to sagittal positive work (p=0.015; d=0.80) (Figure 2).

3.3. Muscle Activation

During stance phase of gait, pregnant females in 2T, compared to controls, demonstrated smaller peak gluteus maximus amplitude (p=0.044; d=0.66). EMG amplitude for the erector spinae, gluteus maximus, and gluteus medius did not differ during 3T compared to controls. Post-partum females, compared to controls, demonstrated smaller average gluteus maximum amplitude (p=0.027; d=0.71) (Figure 3).

3.4 K*inematics*

Pregnant females in 2T, compared to controls, demonstrated smaller peak hip extension (p=0.032: d=0.71), greater peak knee flexion (p=0.039: d=0.69), and smaller peak knee adduction angles (p=0.022: d=0.28) (Table 3). There were no statistically significant differences in kinematics during 3T or post-partum, as compared to controls.

4. DISCUSSION

This study demonstrates for the first time that pregnant females, compared to nulliparous controls, demonstrate differences in lower extremity moments, work, and muscle activation during gait and that many differences persist post-partum. Few studies have evaluated lower extremity kinetics [17, 18, 30] in pregnant and post-partum females and most previous work normalized moments to current body mass, potentially underestimating changes in joint demand throughout pregnancy, as the joint itself has not necessarily increased in size or load capacity. In the current study, despite relatively small differences in peak kinematics (less than 4°), which only reached significance during 2T, lower extremity kinetics, normalized to pre-pregnancy mass at all time points, were significantly altered during pregnancy as compared to nulliparous controls. Overall, pregnant and post-partum females, compared to controls, demonstrated greater moments, work, and percent contribution to work at the knee and ankle, and relative disuse of the hip, as indicated by reduced sagittal contribution and muscle activation at the hip.

4.a. Frontal Plane Kinetics

Peak hip abductor moments were greater at all time points in pregnant participants compared to control participants. This is consistent with previous reports of increased hip abductor moments during 3T compared to 1 year post-partum [17]. Previous research has identified a wide-based gait pattern with increased lateral translation at the trunk [23], which they referred to as a "waddling" gait. This increased sway with gait during pregnancy may potentially contribute to increased frontal plane moments during and after pregnancy and could be relevant with respect to balance and stability [23], but more research is needed to determine the factors contributing to increased hip abductor moments during and after pregnancy. Of note, increased internal knee abductor moments were also observed 3T and post-partum. Increased internal knee abductor moments (and associated increases in moment impulses) are associated with increased risk for the development of knee osteoarthritis over time [31]. The persistence of this finding post-partum could increase the risk of future knee osteoarthritis in this population.

4.b. Sagittal Plane Kinetics and Muscle Activation

With respect to the sagittal plane, pregnant females demonstrated greater utilization of the ankle relative to the hip during pregnancy. Pregnant females during 2T, compared to controls, demonstrated greater ankle negative work, greater percent contribution of the ankle to negative work (47% vs 37%), and smaller relative contribution of the hip (29% vs 36%). Greater percent contribution of the ankle and smaller percent contribution of the hip to negative work indicates that power absorption throughout stance is performed more by the ankle relative to the hip during second trimester. Concurrently, pregnant females in the second trimester, compared to controls, demonstrated smaller peak gluteus maximus muscle activation amplitude during stance phase of gait. Together, these data suggest that during 2T pregnant females demonstrate relative disuse of the hip at a time when body mass is increasing and body mass distribution is changing with the greatest increases at the abdomen [32]. Additionally, the gluteus maximus muscles provide force closure to the sacroiliac joint [33]; therefore, decreased gluteal activation during 2T could contribute to low back or sacroiliac pathology [34], particularly in the presence of decreased ligamentous pelvic stability and increased body mass [35].

Pregnant females during 3T, compared to controls, demonstrated greater ankle plantarflexor and ankle dorsiflexor moments during stance phase of gait. Positive and total lower extremity work were greater 3T compared to controls with significantly greater negative and total ankle work. These greater moments and work are not surprising given the greater body mass in pregnant females during third trimester compared to the nulliparous group. Although greater hip extensor moments have been reported during 3T as compared to 1 year post-partum [17], there were no significant differences in sagittal hip moments during 3T, compared to controls in the current study. Therefore, despite greater body mass, pregnant females did not demonstrate greater hip extensor moments to propel the body forward. However, unlike during 2T, the percent contribution of the lower extremity joints to sagittal plane work did not statistically differ during 3T, compared to controls. It is possible the relative work contribution of each joint returns to more typical levels by 3T as pregnant participants have had time to adapt to increased weight and altered weight distribution over the course of pregnancy. It is also possible that during 3T pregnant females must increase sagittal loading to some degree throughout the lower extremity to accommodate the larger increases in weight, as opposed to the increases occurring primarily at the ankle during 2T.

Post-partum females, compared to controls, demonstrated greater peak ankle dorsiflexor moments and increased positive and total lower extremity work with significantly greater positive knee work. The percent contribution of the knee to sagittal positive work was greater post-partum, compared to controls. Therefore, joint loading remains high during the early post-partum period (4-6 months) despite a non-significantly different mean body mass post-partum. Increased joint moments and work post-partum could potentially contribute to the continued increased prevalence of low back, pelvic, and lower extremity pain during this period. Post-partum females also demonstrated smaller average gluteus maximus muscle activation during stance phase compared to controls. A smaller activation of the gluteal muscles during a time of continued ligamentous laxity, particularly among nursing mothers, may contribute to reduced force closure and stability and increased prevalence of low back or pelvic pain post-partum [33, 34]. Additionally, these data indicate that atypical joint loading and muscle activation persist post-partum and utilization of a post-partum group for biomechanical comparisons may not be the optimal "control" group.

4.c. Limitations

The pregnant participants were heterogeneous with respect to number of previous pregnancies and method of delivery (vaginal vs cesarean), which could affect findings. There are limitations associated with the use of surface EMG due to potential cross-talk among muscles and with normalizing EMG data to peak activation during gait. Due to concerns regarding use of intramuscular EMG and maximum voluntary isometric contraction testing during pregnancy, these methods were deemed necessary. Furthermore, longitudinal gait assessment before, during, and after pregnancy may be the most methodologically sound approach to determine gait adaptations over time. However, there are logistical difficulties with recruiting prior to pregnancy. Therefore, a nulliparous control group was used as a proxy for pre-pregnancy gait.

4.d. Conclusions

Overall, this study demonstrates that joint loading at the knee and ankle are greater during pregnancy and that some differences persist after pregnancy. Concurrently, there were indications of reduced sagittal contribution and activation of the hip. Understanding these gait differences between pregnant and nulliparous females will inform future studies aimed at determining if and how these gait variables relate to orthopedic pain in this population.

Conflict of Interest Statement- there are no conflicts to declare

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Table 1. Subject Demographics (Mean (Standard Deviation))

	Pregnant Females			Nulliparous Controls
	Second Trimester	Third Trimester	Post-partum	
Age (years)	31.6 (SD 3.4)			32.1 (SD 4.7)
Height (cm)	167.7 (SD 3.9)			165.3 (SD 6.0)
Mass (kg)	**73.8 (SD 11.7) ***	**79.4 (SD 12.0)***	**70.3 (SD 13.1)**	**64.8 (SD 9.7)**
Gait velocity (m/s)	1.45 (SD 0.14)	1.51 (SD 0.10)	1.55 (SD 0.10)	1.54 (SD 0.18)

* Significant difference compared to nulliparous ($p<0.05$)

Table 2. Peak Moments during Stance Phase of Gait (Nm/kg) (Mean (Standard Deviation)). Pregnant female moments are normalized to pre-pregnancy body mass at all time points and nulliparous control moments are normalized to current body mass.

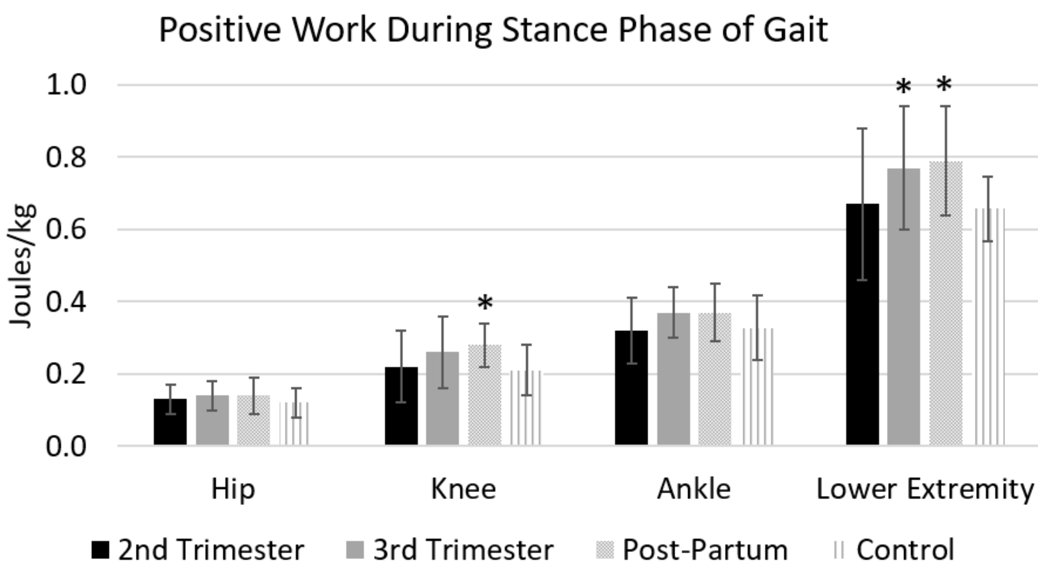
	Pregnant Females			Nulliparous Controls
	Second Trimester	Third Trimester	Post-partum	
Hip Flexor	0.85 (SD 0.23)	1.02 (SD 0.27)	1.08 (SD 0.22)	0.99 (SD 0.22)
Hip Extensor	-0.91 (SD 0.20)	-0.98 (SD 0.19)	-0.95 (SD 0.15)	-0.94 (SD 0.23)
Hip Abductor	**1.15 (SD 0.16)***	**1.27 (SD 0.20)***	**1.17 (SD 0.20)***	**1.04 (SD 0.14)**
Knee Flexor	0.43 (SD 0.11)	0.46 (SD 0.13)	0.39 (SD 0.09)	0.44 (SD 0.14)
Knee Extensor	-0.76 (SD 0.32)	-0.86 (SD 0.23)	-0.85 (SD 0.22)	-0.72 (SD 0.26)
Knee Abductor	0.55 (SD 0.15)	**0.66 (SD 0.17)***	**0.63 (SD 0.14)***	**0.54 (SD 0.11)**
Ankle Dorsiflexor	0.36 (SD 0.12)	**0.39 (SD 0.09)***	**0.39 (SD 0.09)***	**0.32 (SD 0.07)**
Ankle Plantarflexor	-1.57 (SD 0.14)	**-1.70 (SD 0.11)***	-1.52 (SD 0.14)	**-1.51 (SD 0.17)**

* Significant difference compared to nulliparous ($p<0.05$)

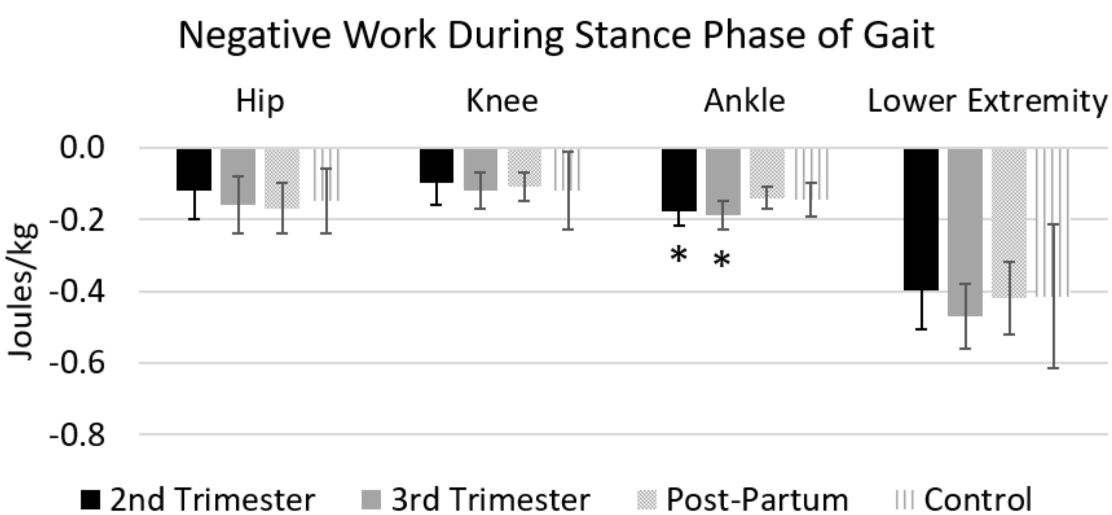
Table 3. Peak Kinematics During Stance Phase of Gait (Mean (Standard Deviation))

	Pregnant Females			Nulliparous Controls
	Second Trimester	Third Trimester	Post-partum	
Trunk Flexion	2.9◦ (SD 6.5◦)	5.1◦ (SD 7.0◦)	4.6◦ (SD 6.6◦)	5.6◦ (SD 6.3◦)
Trunk Extension	-0.7◦ (SD 6.7◦)	1.8◦ (SD 7.0◦)	0.5◦ (SD 6.5◦)	1.0◦ (SD 6.2◦)
Trunk Ipsilateral Obliquity	3.4◦ (SD 2.2◦)	3.7◦ (SD 1.9◦)	4.0◦ (SD 1.5◦)	4.2◦ (SD 2.3◦)
Trunk Contralateral Obliquity	-2.8◦ (SD 2.1◦)	-3.2◦ (SD 2.1◦)	-3.3◦ (SD 1.6◦)	-3.0◦ (SD 2.3◦)
Trunk Ipsilateral Rotation	4.1◦ (SD 2.4◦)	4.4◦ (SD 2.1◦)	5.2◦ (SD 2.3◦)	4.5◦ (SD 2.5◦)
Trunk Contralateral Rotation	-5.1◦ (SD 2.5◦)	-5.3◦ (SD 2.2◦)	-5.0◦ (SD 1.8◦)	-5.2◦ (SD 3.0◦)
Pelvis Anterior Tilt	0.8◦ (SD 5.5◦)	-1.7◦ (SD 6.2◦)	0.4◦ (SD 5.7◦)	-0.7◦ (SD 3.7◦)
Pelvis Posterior Tilt	-2.7◦ (SD 6.2◦)	-5.6◦ (SD 6.3◦)	-2.9◦ (SD 5.7◦)	-4.3◦ (SD 3.9◦)
Pelvis Ipsilateral Obliquity	4.2◦ (SD 1.9◦)	4.3◦ (SD 2.1◦)	4.6◦ (SD 1.8◦)	4.1◦ (SD 1.8◦)
Pelvis Contralateral Obliquity	-2.2◦ (SD 1.7◦)	-2.5◦ (SD 2.1◦)	-3.0◦ (SD 1.5◦)	-2.5◦ (SD 1.5◦)
Pelvis Ipsilateral Rotation	3.7◦ (SD 2.9◦)	4.6◦ (SD 3.6◦)	4.4◦ (SD 2.3◦)	3.5◦ (SD 3.8◦)
Pelvis Contralateral Rotation	-5.4◦ (SD 3.0◦)	-5.6◦ (SD 3.4◦)	-6.3◦ (SD 3.0◦)	-7.1◦ (SD 3.4◦)
Hip Flexion	22.8◦ (SD 7.7◦)	19.4◦ (7.1◦)	21.3◦ (SD 9.2◦)	19.3◦ (SD 5.5◦)
Hip Extension	**-15.5◦ (SD 6.4◦) ***	-20.3◦ (SD 8.5◦)	-18.0◦ (SD 9.1◦)	**-19.3◦ (SD 4.0◦)**
Hip Abduction	-0.5◦ (SD 3.3◦)	-0.4◦ (SD 3.0◦)	-0.9◦ (SD 3.2◦)	-0.4◦ (SD 3.0◦)
Hip Adduction	-10.6◦ (SD 2.7◦)	-10.4◦ (SD 3.8◦)	-10.4◦ (SD 3.7◦)	-9.7◦ (SD 2.8◦)
Hip Internal Rotation	3.3◦ (SD 3.1◦)	5.7◦ (SD 4.1◦)	6.8◦ (SD 5.3◦)	4.4◦ (SD 4.3◦)
Hip External Rotation	-5.9◦ (SD 3.0◦)	-4.6◦ (SD 4.4◦)	-3.4◦ (SD 5.3◦)	-5.2◦ (SD 4.7◦)
Knee Flexion	**48.5◦ (SD 4.2◦) ***	47.8◦ (SD 5.6◦)	47.8◦ (SD 4.9◦)	**45.0◦ (SD 5.8◦)**
Knee Extension	0.5◦ (SD 4.2◦)	-0.5◦ (SD 4.1◦)	-0.3◦ (SD 3.7◦)	-0.8◦ (SD 4.6◦)
Knee Abduction	5.8◦ (SD 2.4◦)	6.1◦ (SD 3.3◦)	5.9◦ (SD 2.8◦)	5.5◦ (SD 3.1) ◦
Knee Adduction	**0.6◦ abduction (SD 2.7◦) ***	0.3◦ adduction (SD 3.3◦)	2.1◦ adduction (SD 3.2◦)	**1.3◦ adduction (SD 2.3◦)**
Ankle Dorsiflexion	13.9◦ (SD 3.4◦)	12.7◦ (SD 2.2◦)	11.9◦ (SD 2.2◦)	12.5◦ (SD 2.3◦)
Ankle Plantarflexion	-14.8◦ (SD 6.2◦)	-16.3◦ (SD 6.4◦)	-18.5◦ (SD 6.6◦)	-15.4◦ (SD 4.1◦)

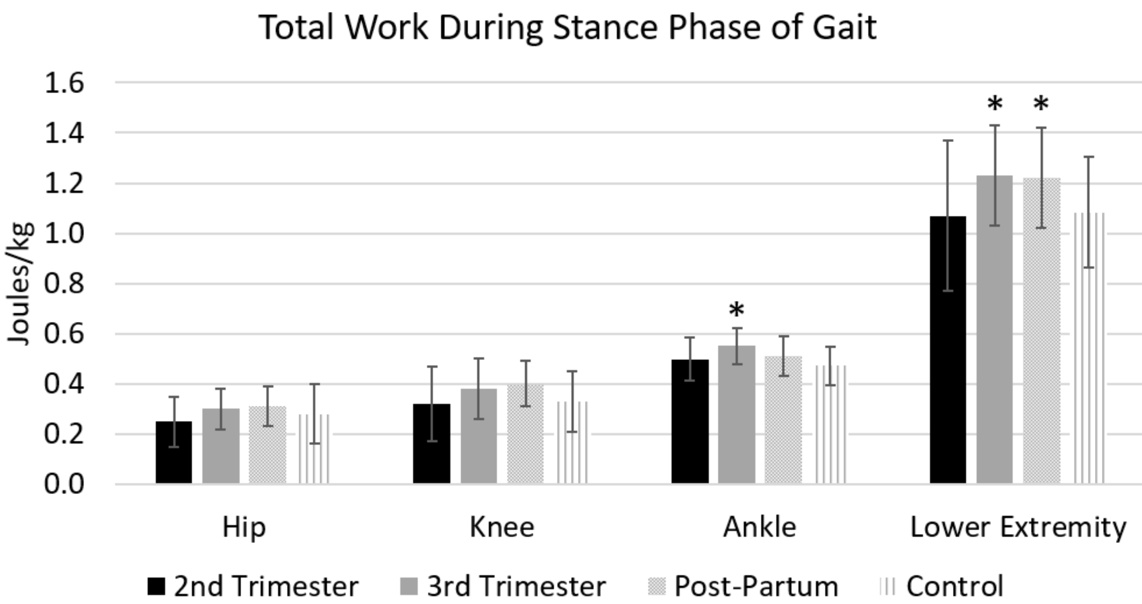
* Significant difference compared to nulliparous ($p<0.05$)


Positive Work During Stance Phase of Gait
1.0
0.8
0.6
0.4
0.2
0.0
Joules/kg
*
*
*
Hip
Knee
Ankle
Lower Extremity
2nd Trimester
3rd Trimester
Post-Partum
Control

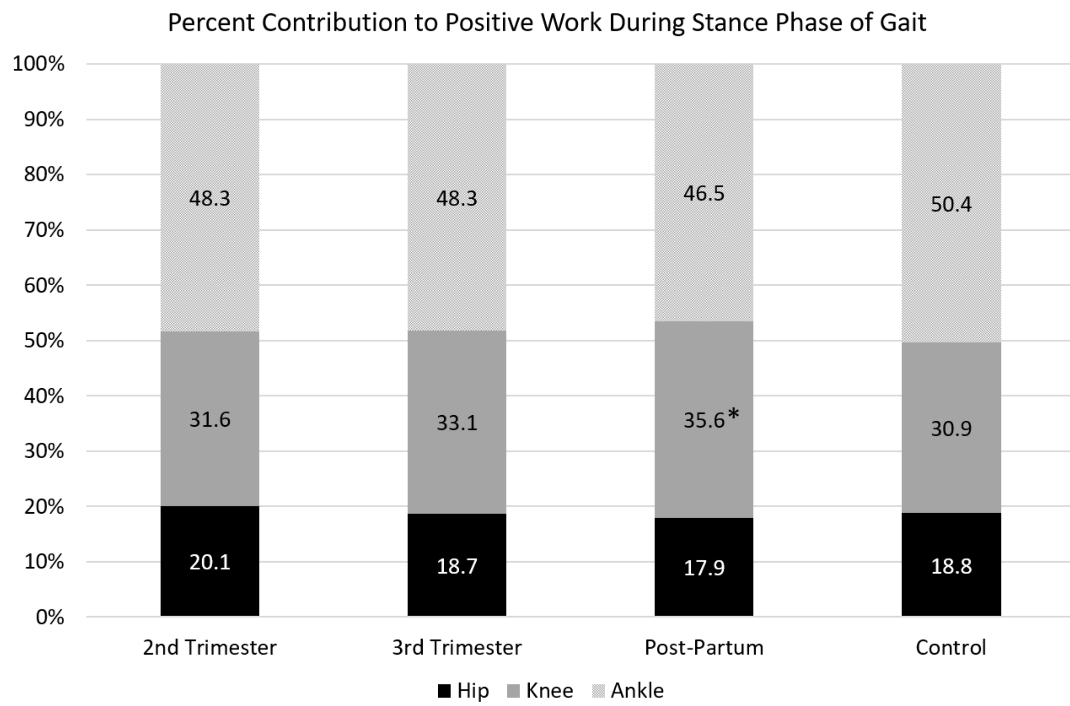
A)


Negative Work During Stance Phase of Gait
Hip
Knee
Ankle
Lower Extremity
0.0
-0.2
-0.4
-0.6
-0.8
Joules/kg
*
*
2nd Trimester
3rd Trimester
Post-Partum
Control

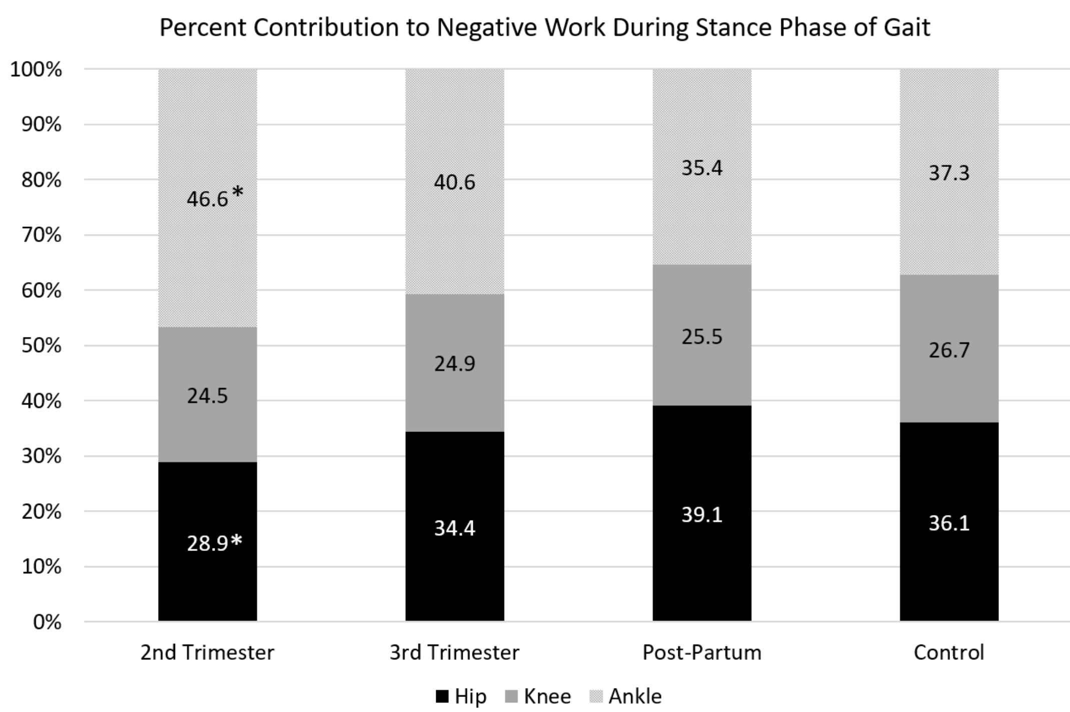
B)


Total Work During Stance Phase of Gait
Joules/kg
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
*
*
*
Hip
Knee
Ankle
Lower Extremity
2nd Trimester
3rd Trimester
Post-Partum
Control

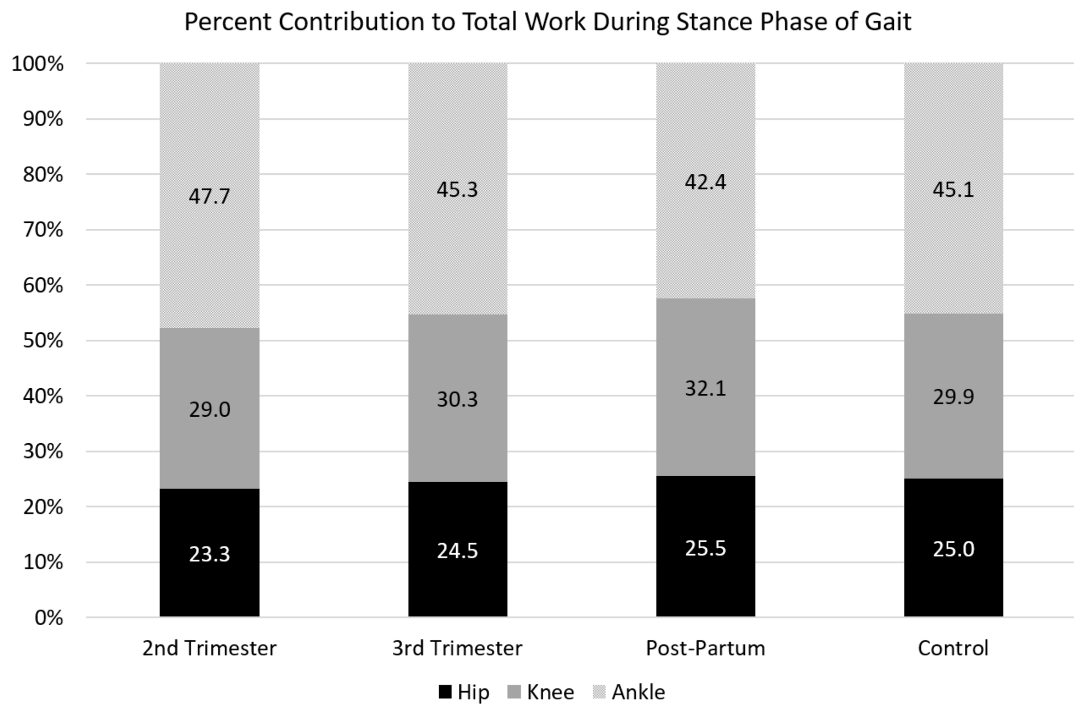
C)


Percent Contribution to Positive Work During Stance Phase of Gait
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
48.3
48.3
46.5
50.4
31.6
33.1
35.6*
30.9
20.1
18.7
17.9
18.8
2nd Trimester
3rd Trimester
Post-Partum
Control
Hip
Knee
Ankle

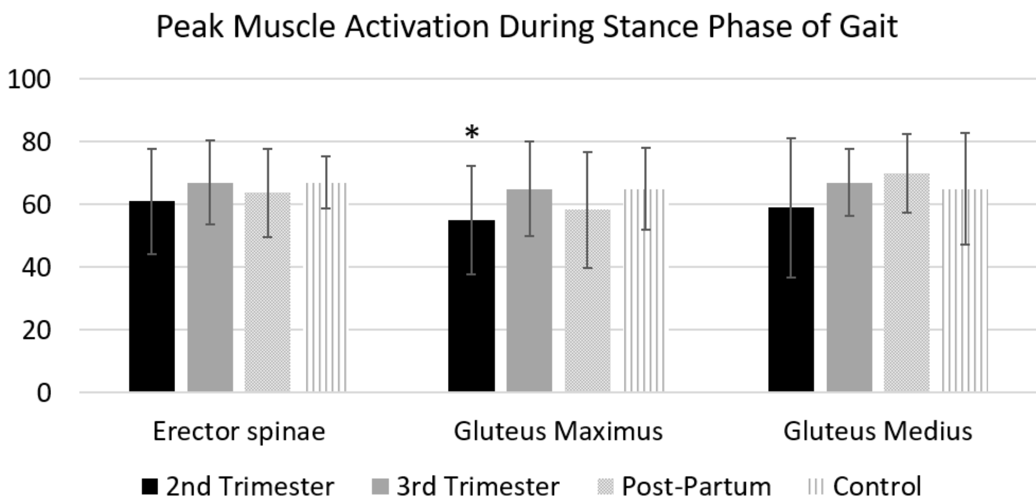
A)


Percent Contribution to Negative Work During Stance Phase of Gait
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
46.6*
40.6
35.4
37.3
24.5
24.9
25.5
26.7
28.9*
34.4
39.1
36.1
2nd Trimester
3rd Trimester
Post-Partum
Control
Hip
Knee
Ankle

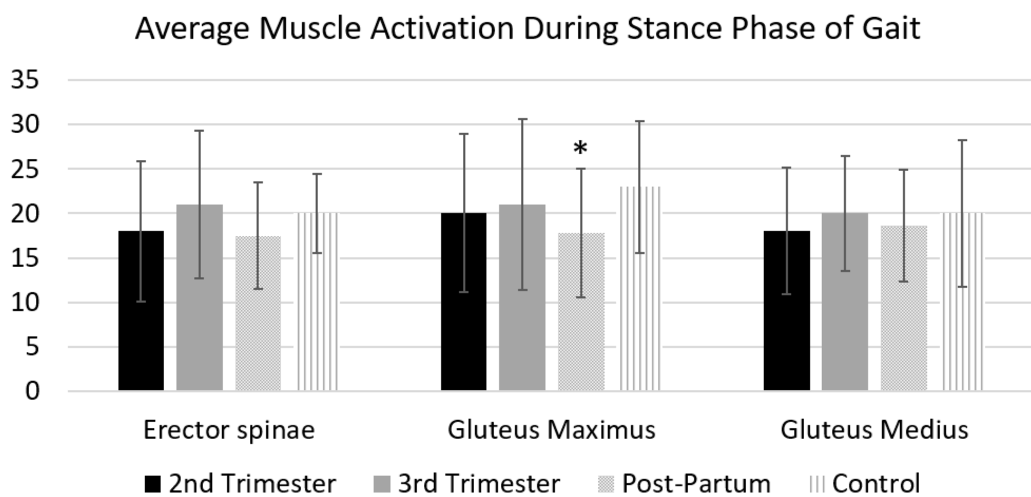
B)


Percent Contribution to Total Work During Stance Phase of Gait
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
47.7
45.3
42.4
45.1
29.0
30.3
32.1
29.9
23.3
24.5
25.5
25.0
2nd Trimester
3rd Trimester
Post-Partum
Control
Hip
Knee
Ankle

C)


Peak Muscle Activation During Stance Phase of Gait
100
80
60
40
20
0
*
Erector spinae
Gluteus Maximus
Gluteus Medius
2nd Trimester
3rd Trimester
Post-Partum
Control

A)


Average Muscle Activation During Stance Phase of Gait
35
30
25
20
15
10
5
0
*
Erector spinae
Gluteus Maximus
Gluteus Medius
2nd Trimester
3rd Trimester
Post-Partum
Control

B)

Figure 1. Positive (A), negative (B), and total (C) lower extremity sagittal work during stance phase of gait in pregnant females during second trimester, third trimester, 4-6 months post-partum, and in matched, nulliparous females. Pregnant female work is normalized to pre-pregnancy body mass at all time points and nulliparous control work is normalized to current body mass. * indicates statistically significant ($p<0.05$) from the nulliparous controls

Figure 2. Percent contribution of the hip, knee, and ankle to positive (A), negative (B), and total (c) lower extremity work during stance phase of gait in pregnant females during second trimester, third trimester, 4-6 months post-partum, and in matched, nulliparous females. * indicates statistically significant ($p<0.05$) from the nulliparous controls

Figure 3. Peak (A) and average (B) gluteus maximus surface electromyographic amplitude during second trimester, third trimester, 4-6 months post-partum, and in matched, nulliparous controls. * indicates statistically significant ($p<0.05$) from the nulliparous controls