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Abstract

Background: The purpose of this study was to compare gait kinematics, kinetics, and muscle activation between pregnant females with high and low scores for low back and/or pelvic girdle pain during and after pregnancy.

Methods: Twenty participants tested during second trimester, third trimester, and again post-partum. At each session, motion capture, force plates, and surface electromyography data were captured during self-selected velocity over-ground walking. Participants completed the Quebec Back Pain Disability Scale (QBPDS) and were assigned to high (QBPDS $\geq$ 15) or low pain groups (QBPDS < 15) based on third trimester scores. Two-way mixed model ANOVAs were used to compare high and low pain groups over time.

Findings: Nine participants met the high pain group criteria and 11 were low pain. During second trimester the high pain group compared to the low pain group demonstrated smaller peak hip flexor moments, total hip work, percent hip contribution to work, and larger percent ankle contribution to work. Pregnant females demonstrated greater hip, knee, and ankle moments, ankle work, and gluteus maximus muscle activation third trimester than second trimester.

Interpretation: Reduced hip and greater ankle contribution to work in the high pain group during second trimester could indicate decreased hip utilization early in pregnancy and may contribute to disability as pregnancy progresses. It is also possible kinetic differences during second trimester reflect an early strategy to reduce pain by avoiding hip joint loading. Increased moments and work during third trimester indicate a clinical imperative to better prepare pregnant females to accommodate increased joint loading and muscular demand.

Key Words: Perinatal, movement analysis, kinematics, kinetics, electromyography, work

1. Introduction

Over half of pregnant individuals experience low back and/or pelvic girdle pain (LB/PGP) [1-3], which has been reported to be associated with depression and functional disability [4-6]. Physical discomfort and LB/PGP are factors that commonly prevent pregnant females from participating in the recommended amount of physical activity [7,8] despite improved maternal and fetal health outcomes among more active pregnant females [9,10]. Furthermore, the occurrence of LB/PGP during pregnancy increases the likelihood of LB/PGP post-partum [11] and postpartum LB/PGP continues to be associated with depression and functional disability [12,13]. Due to the anatomical and physiological changes during pregnancy, it is important to understand how pregnant individuals with high and low levels of pain move, load their joints, and use their muscles. In particular, identification of neuromuscular adaptations during gait may be meaningful because it is a common activity of daily living [14] which is often associated with pain during pregnancy [15].

Previous research indicates reduced gait velocity and altered trunk, pelvis, and hip kinematics in pregnant females with pelvic girdle pain as compared to those without [16,17]. While kinematic findings have been reported, there is a paucity of data comparing joint loading or muscle activation between pregnant females with high and low scores for LB/PGP. In particular, it is important to understand if pregnant individuals who develop LB/PGP have different demands on the pelvis or hip joints and muscles. Stability of the sacroiliac joint relies on form closure (i.e. passive stability from bony congruence and ligamentous support) and force closure (i.e. lateral forces and friction such as muscular compression from gluteus maximus and in response to the ground reaction force) [18]. Because ligamentous laxity increases throughout pregnancy [19], force closure as a result of joint loading and muscle activation of the hip and pelvis may become even more important and clinically relevant to PGP. Additionally, non-pregnant individuals with low back pain demonstrate weak hip musculature, increased erector spinae muscle activation, and altered hip power and work compared to pain free individuals [20-22], indicating that hip kinetics may be important with respect to low back pain during pregnancy.

Previous work has investigated gait adaptations in joint loading during and after pregnancy regardless of pain status. Concurrent with increased mass and altered mass distribution during pregnancy [23], pregnant females in the third trimester (3T) demonstrate greater lower extremity joint moments and work compared to non-pregnant females [24,25]. Interestingly, pregnant females in the second trimester (2T) compared to non-pregnant females demonstrate smaller relative sagittal hip work, greater ankle work, and smaller gluteus maximus muscle amplitude compared to non-pregnant females [25]. Therefore, smaller gluteal activation and the associated decreased force closure of the sacroiliac joint [26] along with decreased work at the hip (potentially related to hip weakness) might contribute to low back or sacroiliac pathology [27] at a time when ligamentous laxity and body mass increases make these regions susceptible to injury [19,28].

Therefore, the purpose of this study was to compare lower extremity gait kinematics, kinetics (moments, work, and work distribution), and muscle activation between pregnant females with high and low scores for LB/PGP and across three time points during and after pregnancy. We hypothesized that pregnant females with

LB/PGP would demonstrate smaller hip and larger ankle moments, work, and percent contribution to lower extremity work, greater erector spinae muscle activation, and lower hip muscle activation during 2T and 3T compared to those with low levels of pain. Consistent with previous research, we hypothesized that lower extremity joint moments and work would be greater during 3T compared to 2T and post-partum.

2. Methods

2.1 Participants

Pregnant females were eligible if they were 19-50 years old and in the first or second trimester at the time of recruitment. Any number of previous pregnancies was allowed. Exclusion criteria included a history of back surgery or contraindications to moderate intensity exercise. Twenty-four pregnant females were recruited; however, one participant experienced medical complications (hypotension during pre-testing screening for the first testing session) and withdrew, one did not complete 3T testing due to concern of exacerbating her LBP, and two did not return post-partum due to scheduling conflicts. Therefore, 20 participants completed all time points and were included in analyses. All participants signed the University IRB approved informed consent and obtained written consent from their treating Obstetrician or mid-wife. Data from these participants has been reported previously as compared to a cohort of females who had never been pregnant [25]. Additionally, participants completed the Quebec Back Pain Disability Scale (QBPDS) and a brief clinical examination including the posterior pelvic pain provocation test (recommended for assessing potential PGP) [29].

2.2 Instrumentation

Lower extremity kinematics and kinetics were obtained using an 8-camera motion capture system (Qualisys, Gothenburg, Sweden, 100 Hz sampling rate) and a grid of 5 force plates along the runaway (Bertec, Columbus, OH, USA, 2000 Hz sampling rate). Lower extremity and pelvis segments were defined by 14 mm opto-reflective markers 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. The iliac crest, L5-S1, and acromion markers along with semi-rigid clusters on the thighs, shanks, and heels were used to track the segments. The iliac crest and L5-S1 markers were used to track the pelvis while avoiding potential marker occlusion with increasing abdomen size [25]. The acromion and iliac crest markers were used to define and track the trunk as one segment. A 5 second static calibration trial was collected with all markers, after which non-tracking markers were removed.

Disposable silver/silver-chloride bipolar surface electromyography (EMG) electrodes were utilized on the lumbar erector spinae, gluteus medius, and gluteus maximus muscles of the dominant limb according to standard recommendations [30]. Hip and spine muscles were investigated due to the potential influence on LB/PGP [20-22,31]. A wireless 16 Channel EMG System (Delsys Trigno, Natick, MA, USA) was used to sample EMG data at 2000 Hz.

2.3 Procedures

This was a longitudinal study with the same participants testing on three occasions: 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). Participants completed seven successful gait trials [32] at self-selected velocity across a 16-meter walkway with the instruction to “walk as if you have someplace to be, but you are not late.” A trial was successful if the dominant foot landed within the force plate and gait velocity was within 10% of mean velocity of the first three trials as measured via photoelectric triggers. Qualisys Track Manager (QTM; Qualisys, Gothenburg, Sweden) was used for data collection, integration, synchronization, and export.

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 in Visual 3D software, Version 4 (C-motion Inc., Rockville, MD, USA). A cardan sequence of mediolateral (X), anteroposterior (Y), and vertical (Z) was used. Kinematics and kinetics for each subject were averaged across the seven trials for the dominant limb. Peak trunk and pelvis relative to the lab coordinate system, hip, knee, and ankle kinematics and peak hip, knee, and ankle internal moments were calculated. Kinetic data were normalized to pre-pregnancy body mass at all time points to provide meaningful comparisons which reflect adaptations in joint demand as a result of mass changes during and after pregnancy [25].

A custom code in Matlab, Version 9.5 (MathWorks Inc., Natick, MA, USA) was used to determine mean sagittal plane total work across the seven trials for the hip, knee, and ankle as the sum of the absolute value of the area under the positive and negative portions of the power curve. Total sagittal plane lower extremity mechanical work was calculated by summing total work across the hip, knee, and ankle, respectively. Percent contribution of the hip, knee, and ankle to total lower extremity work was calculated by dividing total work of the hip, knee, and ankle by total work for the lower extremity and multiplying by 100.

EMG data were bandpass filtered at 10 to 450 Hz and notch filtered at 60 Hz, full-wave rectified, and low-pass filtered at 6 Hz to create a linear envelope [33]. The peak value obtained for each muscle across the entire gait cycle of the seven trials was used to amplitude normalize EMG data [34]. Peak and average muscle activation were calculated for the ipsilateral limb during stance phase of gait using a custom-written Matlab code Version 9.5 (MathWorks Inc., Natick, MA, USA).

Participants with a QBPDS greater than or equal to 15 (selected based on the minimal detectible change score [35]) during 3T were assigned to the high pain group and those less than 15 were assigned to the low pain group. Grouping remained the same at all time points and was determined only by pain during 3T (an individual in the high pain group could have a low or high QBPDS score during the other two time points, but was considered a member of the pain group for all comparisons).

2.5 Statistical analysis

The dependent variables of interest were gait velocity, peak sagittal and frontal plane moments normalized to pre-pregnancy body mass, sagittal plane total work and percent contribution to work of the hip, knee, and ankle, and peak and average percent amplitudes of the ipsilateral erector spinae, gluteus medius, and gluteus maximus muscles during stance phase of gait. Peak sagittal, frontal, and transverse plane trunk, pelvis, and hip, sagittal and frontal plane knee, and sagittal plane ankle kinematics were also calculated to inform interpretation of joint kinetics. Two-way mixed model ANOVAs were used to assess variables of interest between those with high and low scores for

LB/PGP and across the three time points. Independent and paired t-tests were used when appropriate to assess differences between groups and across time points, respectively. Differences between high and low pain groups for LB/PGP with respect to the posterior pelvic provocation test were assessed using chi-square tests at each time point to provide additional insight regarding clinical presentation. Statistics were analyzed using SPSS software, Version 28.0 (SPSS, Inc., Chicago, IL), $\alpha=0.05$. Hedges' g effect sizes were calculated for statistically significant findings due to the different group sizes and were interpreted as small (0.2), medium (0.5), and large (0.8) [36].

3. Results

3.1 Participant QBPDS, demographics, and gait velocity

Nine participants met the criteria for the high pain group and 11 were classified as low pain based on 3T scores (Table 1). Two of the participants in the high pain group and zero participants in the low pain group would have met the pain group criteria based on 2T scores. There was a significant group by time interaction for QBPDS (P< 0.001). The high pain group had worse QBPDS scores during 2T and 3T compared to the low pain group (P=0.006 and g=1.401 and P <0.001 and g=2.868). Within the high pain group, scores were worse during 3T compared to 2T and post-partum (P<0.001 and g=1.757 and P<0.001 and g=2.872) and were worse during 2T compared to post-partum (P=0.04 and g=1.341). A significantly greater proportion of individuals in the high pain group compared to the low pain group had a positive posterior pelvic pain provocation test during 3T (100% vs 55% reported pain; χ^2=5.455; P=0.020); however, there were no significant group differences with the posterior pelvic pain provocation test during 2T or post-partum (78% vs 46% reported pain χ^2=2.155; *P*=0.142 and 33% vs 64% reported pain χ^2=1.818; *P*=0.178, respectively). There were no significant interactions or main effects of pain grouping for age, height, mass, or gait velocity (*P*>0.05). There were significant main effects of time on body mass and gait velocity (*P*<0.001 and *P*=0.004). Post hoc analyses revealed that mass was greater during 3T compared to 2T and post-partum (*P*<0.001 and g=0.462 and *P*<0.001 and g=0.715), mass was greater during 2T compared to post-partum (*P*<0.001 and g=0.283), and gait velocity was slower during 2T compared to post-partum (*P*=0.02 and g=0.780; Table 1).

3.2 Kinematics

There were no significant interactions with respect to peak kinematics. There was a main effect of pain grouping on peak pelvis ipsilateral rotation (*P*=0.037). During postpartum, the high pain group compared to the low pain group demonstrated greater pelvis ipsilateral rotation (*P*=0.003 and g=1.544). There were main effects of time for peak trunk flexion and extension (*P*=0.013 and *P*=0.028), hip internal rotation (*P*=0.007), knee adduction (*P*=0.001), and ankle dorsiflexion and plantarflexion angles (*P*=0.009 and *P*<0.001). Post hoc analysis revealed that peak hip internal rotation angles (*P*=0.007 and g=0.672) were smaller during 2T compared to 3T, peak trunk flexion (*P*=0.048 and g=0.440), hip internal rotation (*P*=0.007 and g=0.809), and ankle plantarflexion angles (*P*<0.001 and g=0.577) were smaller and peak knee adduction (*P*=0.017 and g=0.540) and ankle dorsiflexion angles (*P*=0.011 and g=0.692) were greater during 2T compared to post-partum, and peak trunk extension angles (*P*=0.005 and g=0.471) were greater and peak trunk flexion (*P*=0.005 and g=0.491), peak knee adduction (*P*=<0.001 and g=0.905) and ankle plantarflexion angles (*P*<0.001 and g=0.354) were smaller during 3T compared to post-partum (Table 2). Time series for kinematic variables with significant findings are available in Supplementary appendix A.

3.3 Peak Moments

There were significant main effects of pain grouping on peak hip flexor (*P*=0.025) and ankle dorsiflexor moments (*P*=0.019). During 2T the high pain group compared to the low pain group demonstrated smaller peak hip flexor moments (*P*<0.001 and g=1.869) and during 3T the high pain group compared to the low pain group demonstrated smaller peak ankle dorsiflexor moments (*P*=0.006 and g=0.756). There were significant main effects of time on peak hip flexor (*P*<0.001), hip abductor (p=0.011), knee flexor (*P*=0.013), knee abductor (*P*=0.004), and ankle plantarflexor moments (*P*<0.001). Post-hoc analysis revealed that peak hip flexor (*P*=0.004 and g=0.67), hip abductor (*P*=0.002 and g=0.633), knee abductor (*P*<0.001 and g=0.688), and ankle plantarflexor moments (*P*<0.001 and g=0.951) were smaller during 2T compared to 3T, peak hip flexor (*P*<0.001 and g=1.003) and knee abductor moments (*P*=0.003 and g=0.599) were smaller during 2T compared to post-partum, and peak hip abductor (*P*=0.028 and g=0.458), knee flexor (*P*<0.001 and g=0.523), and ankle plantarflexor moments (*P*<0.001 and g=1.302) were greater during 3T compared to post-partum (Table 3). Time series for moment variables with significant findings are available in Supplementary appendix B.

3.4 Work and Work Distribution

There was a significant group by time interaction for total hip work (*P*=0.026). During 2T, total hip work in the high pain group compared to the low pain group was smaller (*P*=0.016 and g=1.139). Within the high pain group, total hip work was smaller during 2T compared to 3T and post-partum (*P*=0.009 and g=1.360 and *P*=0.006 and g=1.276, respectively). There were significant main effects of time on total knee work (*P*=0.023), total ankle work (*P*=0.014), and total lower extremity work (*P*=0.004). Post hoc analysis revealed that total ankle work (*P*<0.001 and g=0.660) and total lower extremity work (*P*=0.01 and g=0.622) were smaller during 2T compared to 3T and total knee work (*P*=0.033 and g=0.568) and total lower extremity work (*P*=0.019 and g=0.555) were smaller during 2T compared to post-partum (Figure 1).

There was a significant group by time interaction for percent contribution of the hip to total work (*P*=0.019) and for percent contribution of the ankle to total work (*P*=0.015). During 2T, the high pain group compared to the low pain group demonstrated smaller percent contribution of the hip (*P*=0.046 and g=0.926) and greater percent contribution of the ankle to total lower extremity work (*P*=0.018 and g=1.120). Within the high pain group, percent contribution of the hip to total lower extremity work was smaller (*P*=0.039 and g=0.781 and *P*=0.021 and g=0.819, respectively) and percent contribution of the ankle to total work was greater (*P*=0.033 and g=0.946 and *P*=0.004 and g=1.576, respectively) during 2T compared to 3T and post-partum and percent contribution of the ankle to lower extremity work was greater (*P*=0.037 and g=0.561) during 3T compared to postpartum. There was a significant main effect of time on percent contribution of the knee to total work (*P*=0.046). Post hoc analysis revealed that percent contribution of the knee to total lower extremity work was smaller during 2T compared to post-partum (*P*=0.034 and g=0.702; Figure 2).

3.5 EMG

There was a significant group by time interaction for erector spinae average amplitude during stance phase of gait (*P*=0.025). Only within the low pain group, erector spinae average amplitude was greater during 3T compared to post-partum (*P*=0.005 and g=0.770). There was a significant main effect of time for gluteus maximus peak amplitude during stance phase (*P*=0.035). Post hoc analysis revealed that gluteus maximus peak amplitude was smaller during 2T compared to 3T (*P*=0.009 and g=0.750; Table 4). There were no significant differences for gluteus medius amplitude.

4. Discussion

4.1 Summary, Demographics, Outcomes, and Gait Velocity

This study provides the first comprehensive analysis of gait mechanics and muscle activation between pregnant females with high and low scores for LB/PGP during and after pregnancy. Pregnant females who experience LB/PGP during 3T demonstrate smaller peak hip flexor moments and greater ankle relative to hip work during 2T and smaller peak hip flexor moments during 3T. Additionally, during 3T several moment and work variables and gluteus maximus activation were higher across all pregnant participants indicating increased lower extremity demand as pregnancy progressed. In the low pain group erector spinae activation was lower post-partum than during 3T. While there were several statistically significant kinematics differences, the magnitude of these differences was small, potentially limiting clinical meaningfulness.

Although previous research suggests that age and body mass are risk factors for the development of LBP/PGP [37], the high pain and low pain groups in the current study were similar with respect to age, height, and body mass. During post-partum testing, QBPDS were similar between groups with only one participant from the low pain group meeting our criteria for pain; however, one post-partum time point may not fully capture the totality of potential risk of pain in post-partum females. Additionally, though previous studies found that pregnant individuals with LP/PGP had slower self-selected gait velocity [16,17], velocity was not statistically significantly different between groups in the current study at any timepoint. This may be due to instructions in the current study which encouraged purposeful walking. Different task instructions may potentially result in different gait velocities between cohorts. Across pregnant females with high and low pain, gait velocity was greater post-partum as compared to during 2T with a medium effect size, potentially due to previous exposure to procedures or due to no longer being pregnant. It is important to consider this difference when interpreting gait adaptations between 2T and post-partum.

4.2 Kinematics

Attenuated pelvis motion and altered lumbopelvic coordination have been reported in pregnant females with PGP compared to without [16,17], however in the current study, the only significant kinematic difference between high pain and low pain groups was greater pelvis ipsilateral rotation in the high pain group compared to the low pain group post-partum with a large effect size. The presence of altered pelvic rotation between females who previously had pain during pregnancy, even though post-partum LB/PGP related disability was low at the time of post-partum testing, may indicate persistent lumbopelvic adaptations, trunk muscle insufficiency, or changes in pelvic control. Considering that previous research suggests that even 2 years post-partum, greater than one-fifth of females have persistent back pain [38], future studies should tease out potential clinical implications of altered pelvic motion in post-partum females. All other kinematic differences observed were of small or medium effect size with the exception of reduced hip internal rotation during 2T compared to post-partum across females with high and low pain, which likely can be explained by slower gait velocity during 2T compared to post-partum. Smaller peak knee adduction was also observed during 3T compared to post-partum and had a large effect size though the magnitude of this difference was less than 2 degrees.

4.3 Kinetics

Despite relatively small kinematic differences between pregnant females with high and low pain and across females during and after pregnancy, there were several significant kinetic differences with respect to LB/PGP during and after pregnancy. During 2T those who went on to develop pain later in pregnancy demonstrated relative disuse of the hip as indicated by smaller hip moments, work, and percent contribution to work, all with large effect sizes. During 3T, the only significant difference observed between high and low pain groups was smaller ankle dorsiflexor moments with a medium effect size. Lower peak hip flexor (2T) and ankle dorsiflexor moments (3T) in the high pain group compared to the low pain group could possibly relate to attenuation of forces at transition points during gait such as during late stance (peak hip flexor moment) and during weight acceptance (peak ankle dorsiflexor moment) or may be due to potential spatiotemporal differences as have been reported previously [16]; however, spatiotemporal characteristics are beyond the scope of the current paper.

In the high pain group, the contribution of each joint to total lower extremity work fluctuated to a large extent over time (18-20% redistribution between the ankle and the hip from 2T to 3T). In contrast, the low pain group maintained similar distribution across joints throughout pregnancy, with no differences greater than 6% over time for any joint. The smaller moments, work, and percent contribution to work at the hip during 2T in persons who went on to develop LB/PGP may indicate those with relative disuse of the hip were more susceptible to the development of LB/PGP later in pregnancy when body mass increases and demand (moments and work) is greater. This would be consistent with previous research which has linked LBP and hip weakness [20,39]. However, it is important to consider that while pain groups were determined by QBPDS during 3T, QBPDS in the high pain group was already significantly higher during 2T compared to the low pain group; therefore, reduced utilization of the hip early in pregnancy could also be a protective strategy as a result of low back or pelvic girdle pain. The similar percent contributions to work across the lower extremity between participants with high and low pain later in pregnancy may be attributed to the need to increase loading throughout the lower extremity to accommodate increased body mass or could possibly be due to increased time to adapt to the physical changes associated with pregnancy.

Furthermore, the present study demonstrates increased moments and work from 2T to 3T of pregnancy. Additionally, during 3T compared to postpartum, greater hip abductor, knee flexor, and ankle plantarflexor moments were observed with small, medium, and large effect sizes, respectively. Taken together, these results are consistent with previous findings that demand across the lower extremity is increased during 3T [24,25] and reinforces the need to physically prepare pregnant females to accommodate these changes.

4.4 Muscle Activation

The low pain group demonstrated decreased erector spinae activation post-partum while erector spinae muscle activation remained similar across time points in the high pain group. Previous studies indicate that individuals with persistent low back pain demonstrate greater levels of erector spinae activation during gait [22,40,41] which has been hypothesized to potentially increase spinal compressive loading and contribute to pathology over time [42]. Therefore, it is possible that the decreased activation in the low pain group post-partum while the high pain group remained unchanged may be meaningful clinically; however, previous research with this same cohort did not indicate differences in erector spinae muscle activation at any timepoints during and after pregnancy as compared to a group of females that had never been pregnant [25] making it less clear why only the low pain group would demonstrate changes. In addition to the differences between those with high and low pain, the current study revealed increased gluteus maximus EMG amplitude during 3T compared to 2T across pregnant females. The gluteus maximus muscle is an important stabilizer of the sacroiliac joint and increased activation may be necessary in the presence of increased body mass and as joint laxity increases during pregnancy. Similar to the increased joint moments and work, future research is needed to better understand how best to prepare pregnant females for increased gluteus maximus muscle demands. There is a need to understand if specific exercises interventions, such as those targeting the hip, trunk, and pelvic floor musculature better prepare pregnant females for increased muscular demands during pregnancy and reduce orthopedic pathology in this population.

4.5 Limitations

There are several limitations which should be considered when interpreting these data. The relatively small sample size should be considered. Additionally, while gait velocity did not significantly differ between groups, it is possible that small differences in gait velocity could impact biomechanical findings. Therefore, future replication studies are needed to corroborate these findings. It is important to note that LBP and PGP are separate entities, however, they often occur concurrently [43]. The current study did not differentiate between LBP and PGP; instead providing insight regarding factors which may relate to either or both conditions during pregnancy. Our pregnant population was heterogenous with respect to parity and delivery history. It is reasonable to assume that cumulative effects of multiple pregnancies as well as delivery history could influence biomechanics and clinical outcomes, however, we did not have adequate sample size to further investigate the potential influence of these factors. Additionally, this study utilized surface EMG which may be influenced by cross-talk. Furthermore, EMG data were normalized to peak activation during gait due to safety concerns regarding voluntary isometric contraction testing during pregnancy. The testing protocol did not include a pre-pregnancy testing session due to the logistical difficulties with recruiting prior to pregnancy, which makes interpretation of causality more complicated.

5. Conclusions

Pregnant females demonstrated significant adaptions in moments and work throughout the lower extremity during pregnancy, particularly during 3T. Clinically it is imperative to consider how best to prepare pregnant individuals to accommodate increased joint loading and gluteus maximus muscle demand. Additionally, individuals with LB/PGP demonstrated reduced hip and greater ankle contribution to work during 2T but had similar work and work distribution during 3T. Therefore, pregnant females who demonstrate reduced utilization of the hip relative to the ankle may be more likely to develop pain and disability as pregnancy progresses and joint loading increases; however, it is also possible that differences during 2T could reflect early strategies to reduce pain by avoiding loading around the hip. Future research should evaluate LB and PGP separately and determine whether addressing hip weakness or disuse through strengthening or motor training might benefit pregnancy females. Furthermore, additional research should focus on clarifying potential causality.

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TABLE 1. Pregnant Subject Demographics and Disability Scores (Mean + Standard Deviation)

	Second trimester		Third trimester		Post-partum	
	High Pain Group	Low Pain Group	**High** Pain Group	Low Pain Group	**High** Pain Group	Low Pain Group
Age (years)	31.4 + 3.60	31.6 + 3.4				
Height (centimeters)	167.3 + 4.0	167.9 + 3.9				
Mass (kilograms) *βγ δ	73.5 + 8.7	74.1 + 14.1	79.5 + 9.8	79.3 + 14.1	69.2 + 10.6	71.1 + 15.3
Gait Velocity (meters/second) *δ	1.39 + 0.15	1.50 + 0.11	1.50 + 0.12	1.52 + 0.09	1.55 + 0.09	1.55 + 0.11
Quebec Back Pain Disability Scale	**11.1 + 7.4 βδ**	**3.8 + 4.2**	**27.7 + 8.4 βγ**	**4.6 + 4.5**	2.4 + 3.9 γδ	4.1 + 7.0

Variable Name for Significant Interactions are Bolded
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Group Differences Have Bolded Results
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TABLE 2. Peak Kinematics During Stance Phase of Gait (Degrees) (Mean ± Standard Deviation). All pelvis and trunk kinematics are as compared to the lab coordinate system.

	Second trimester		Third trimester		Post-partum	
	High Pain Group	Low Pain Group	**High** Pain Group	Low Pain Group	**High** Pain Group	Low Pain Group
Trunk Flexion *γδ	2.5 ± 3.0	0.8 ± 2.7	1.3 ± 2.9	1.5 ± 3.1	3.3 ± 2.8	2.6 ± 3.4
Trunk Extension *γ	-0.6 ± 3.2	-2.2 ± 2.9	-2.1 ± 3.1	-1.5 ± 3.1	0.0 ± 2.5	-0.7 ± 3.3
Trunk Ipsilateral Obliquity	-0.2 ± 1.2	0.5 ± 1.4	0.3 ± 0.7	0.5 ± 1.0	0.5 ± 1.1	0.5 ± 1.0
Trunk Contralateral Obliquity	-1.9 ± 0.9	-1.1 ± 1.1	-1.4 ± 1.0	-1.3 ± 1.1	-1.3 ± 1.3	-1.2 ± 0.9
Trunk Ipsilateral Rotation	0.5 ± 2.9	1.0 ± 1.8	2.5 ± 3.7	0.6 ± 2.0	1.3 ± 2.4	1.4 ± 2.1
Trunk Contralateral Rotation	-3.8 ± 3.0	-4.5 ± 2.1	-2.1 ± 3.2	-5.0 ± 2.1	-3.3 ± 1.7	-4.7 ± 2.1
Pelvis Anterior Tilt	1.2 ± 5.3	0.5 ± 5.9	0.2 ± 6.8	-3.3 ± 5.4	2.5 ± 6.0	-1.4 ± 4.9
Pelvis Posterior Tilt	-2.1 ± 6.5	-3.2 ± 6.2	-3.5 ± 7.2	-7.4 ± 5.1	-0.6 ± 6.5	-4.7 ± 4.4
Pelvis Ipsilateral Obliquity	4.1 ± 2.3	4.4 ± 1.6	4.6 ± 2.7	4.1 ± 1.5	4.6 ± 1.7	4.6 ± 2.0
Pelvis Contralateral Obliquity	-2.7 ± 1.5	-1.8 ± 1.9	-2.6 ± 2.3	-2.5 ± 2.1	-3.5 ± 1.6	-2.6 ± 1.4
Pelvis Ipsilateral Rotation α	4.4 ± 2.3	3.2 ± 3.4	6.3 ± 3.9	3.3 ± 2.9	**5.9 ± 1.8**	**3.1 ± 1.8**
Pelvis Contralateral Rotation	-5.4 ± 3.3	-5.5 ± 3.0	-4.4 ± 2.9	-6.6 ± 3.6	-6.0 ± 2.4	-6.6 ± 3.5
Hip Flexion	22.7 ± 7.7	22.8 ± 8.0	20.3 ± 7.3	18.6 ± 7.2	24.1 ± 9.1	19.0 ± 8.9
Hip Extension	-13.7 ± 6.1	-17.1 ± 6.6	-19.0 ± 10.4	-21.3 ± 6.9	-15.0 ± 10.0	-20.4 ± 7.9
Hip Abduction	0.3 ± 3.8	-1.2 ± 2.7	1.0 ± 3.4	6.7 ± 2.8	0.5 ± 1.8	-2.1 ± 3.7
Hip Adduction	-10.2 ± 3.5	-10.9 ± 2.0	-10.0 ± 4.9	-10.6 ± 3.0	-9.2 ± 3.0	-11.3 ± 4.1
Hip Internal Rotation *βδ	3.3 ± 3.9	3.3 ± 2.6	6.6 ± 4.5	5.9 ± 3.8	5.8 ± 3.8	7.6 ± 6.4
Hip External Rotation	-6.0 ± 2.9	-5.8 ± 3.3	-4.3 ± 3.9	-4.8 ± 5.1	-4.1 ± 3.1	-2.8 ± 6.7
Knee Flexion	48.1 ± 3.0	48.7 ± 5.1	45.9 ± 5.1	49.3 ± 5.6	48.1 ± 4.6	47.5 ± 5.4
Knee Extension	0.7 ± 4.2	0.4 ± 4.4	-0.8 ± 4.1	-0.3 ± 4.4	0.6 ± 3.5	-1.0 ± 3.8
Knee Abduction	5.2 ± 3.0	6.3 ± 1.9	5.3 ± 4.0	6.7 ± 2.8	4.3 ± 2.4	6.7 ± 3.0

Knee Adduction*δγ	-0.9 ± 3.4	1.2 ± 2.0	-0.7 ± 4.7	0.0 ± 1.6	-2.0 ± 3.3	-2.1 ± 3.3
Ankle Dorsiflexion *δ	13.4 ± 2.3	14.4 ± 4.1	12.2 ± 1.3	13.1 ± 2.7	11.1 ± 2.3	12.7 ± 2.0
Ankle Plantarflexion *γδ	-15.7 ± 6.0	-14.1 ± 6.6	-16.9 ± 6.3	-15.8 ± 6.6	-20.1 ± 6.4	-16.8 ± 6.4

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TABLE 3. Peak Moments during Stance Phase of Gait (Newton-meters/kilogram) (Mean ± Standard Deviation). Moments are normalized to pre-pregnancy body mass at all time points.

	Second trimester		Third trimester		Post-partum	
	Pain Group	Low Pain Group	Pain Group	Low Pain Group	Pain Group	Low Pain Group
Hip Flexor *αβδ	**0.67 ± 0.13**	**1.00 ± 0.19**	0.98 ± 0.30	1.06 ± 0.24	0.99 ± 0.14	1.16 ± 0.24
Hip Extensor	-0.88 ± 0.21	-0.92 ± 0.21	-0.99 ± 0.24	-0.96 ± 0.16	-0.97 ± 0.14	-0.93 ± 0.16
Hip Abductor * βγ	1.11 ± 0.17	1.18 ± 0.15	1.20 ± 0.18	1.32 ± 0.22	1.14 ± 0.19	1.20 ± 0.21
Knee Flexor *γ	0.44 ± 0.10	0.43± 0.12	0.48 ± 0.15	0.44 ± 0.12	0.40 ± 0.12	0.39 ± 0.08
Knee Extensor	-0.65 ± 0.25	-0.84 ± 0.36	-0.84 ± 0.13	-0.89 ± 0.29	-0.91 ± 0.14	-0.88 ± 0.27
Knee Abductor * βδ	0.54 ± 0.19	0.55 ± 0.12	0.65 ± 0.19	0.66 ± 0.15	0.63 ± 0.17	0.64 ± 0.11
Ankle Dorsiflexor α	0.31 ± 0.12	0.40 ± 0.11	**0.33 ± 0.07**	**0.44 ± 0.08**	0.35 ± 0.07	0.42 ± 0.10
Ankle Plantarflexor *βγ	-1.54 ± 0.17	-1.60 ± 0.11	-1.71 ± 0.12	-1.69 ± 0.11	-1.48 ± 0.13	-1.56 ± 0.16

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TABLE 4: Average and Peak Muscle Activation During Stance Phase of Gait (Mean ± Standard Deviation)

	Second trimester		Third trimester		Post-partum	
	Pain Group	Low Pain Group	Pain Group	Low Pain Group	Pain Group	Low Pain Group
Erector Spinae Average	15.0 ± 4.9	20.2 ± 9.0	18.8 ± 5.9	22.2 ± 9.8 δ	19.8 ± 6.2	15.7 ± 5.4 δ
Erector Spinae Peak	59.0 ± 10.4	62.8 ± 20.6	63.2 ± 12.0	69.4 ± 14.4	70.5 ± 12.7	58.2 ± 13.3
Gluteus Maximus Average	18.6 ± 8.4	20.7 ± 9.5	22.0 ± 8.4	20.6 ± 10.9	16.6 ± 8.2	18.8 ± 6.6
Gluteus Maximus Peak *β	51.2 ± 20.3	57.3 ± 15.5	66.8 ± 14.5	63.3 ± 16.3	53.4 ± 23.0	62.2 ± 13.5
Gluteus Medius Average	15.8 ± 6.6	20.4 ± 7.1	20.0 ± 5.9	20.7 ± 7.2	17.8 ± 6.5	19.3 ± 6.4
Gluteus Medius Peak	52.9 ± 24.0	63.6 ± 20.4	69.1 ± 8.8	64.7 ± 12.0	71.0 ± 12.9	69.2 ± 12.9

Variable Name for Significant Interactions are Bolded
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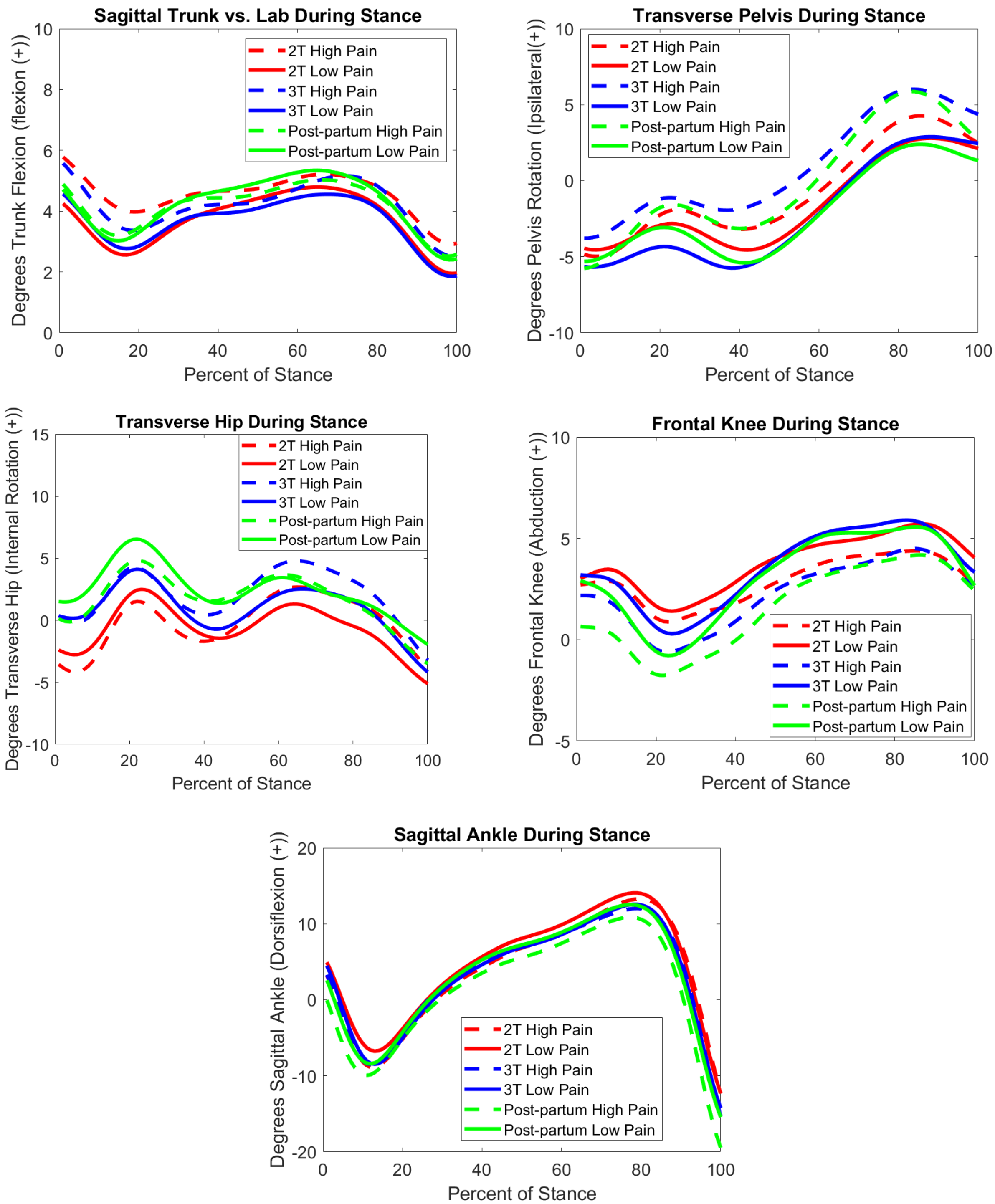
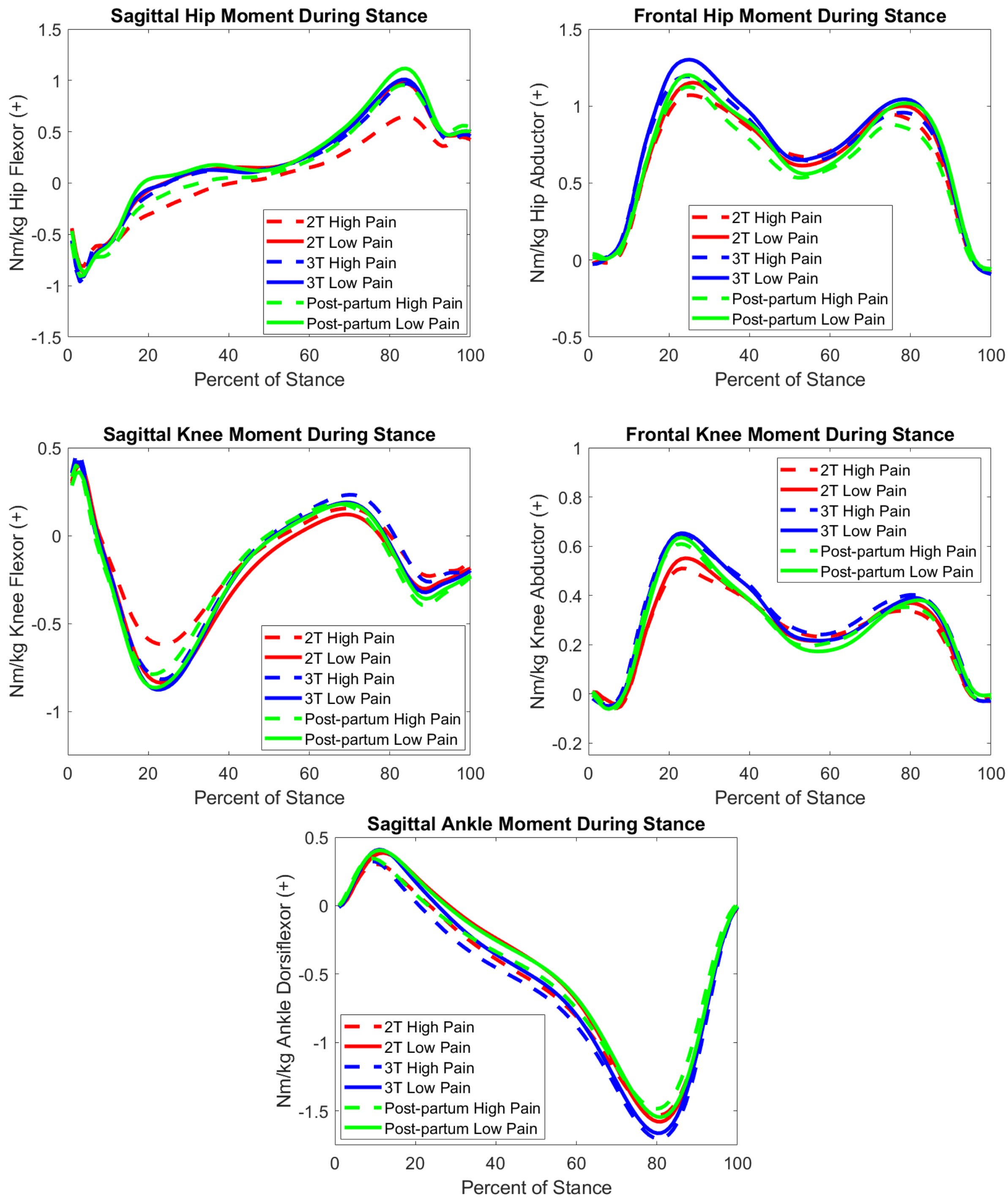


SUPPLEMENTARY APPENDIX A. Time series kinematics during stance phase of gait for significant findings (peak values and statistical results reported in TABLE 2)



SUPPLEMENTARY APPENDIX B) Time series moment graphs normalized to pre-pregnancy body mass for significant findings (peak values and statistical results reported in TABLE 3)