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The Effects Of Advancing Stages Of Pregnancy On Balance And Stair Locomotion In Healthy Females

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Abstract

Background: One in four females fall while pregnant, which may lead to injury, hospitalization, or birth complications. No empirical research has been conducted on single-limb support (SLS) balance or joint kinematics during stair locomotion in pregnant and postpartum females. The aim of this study was to quantify possible alterations to postural control and stair kinematics in advancing stages of pregnancy when compared to non-pregnant females. *Methods:* This cross-sectional study compared eighteen females, consisting of six non-pregnant controls, five 2nd trimester, four 3rd trimester, and three postpartum. Center of pressure excursion area data were obtained during static balance trials on a single force platform for 30s in right limb, left limb, and bilateral conditions (1000 Hz). Sacral velocity and joint range of motion at the knee and ankle joints were collected during stair ascent and descent (200 Hz). Depending on the variable, balance and kinematic results were assessed using separate ANOVAs (α=0.05). *Results:* Single-limb balance was significantly greater than bilateral (p<0.01), but right and left limb conditions were not significantly different from each other among groups (p=0.58). Stair ascent and descent kinematic variables were not significantly different among groups. According to these results, advancing stages of pregnancy did not significantly alter tasks heavily reliant on single-limb support. Therefore, pregnant females with symmetrical limb balance suggests that they may not be in the high-risk category for falls.

Table of Contents

List of Tables

List of Figures

Introduction

One in four females fall during pregnancy, with ten percent falling more than once while pregnant (Dunning, LeMasters, & Bhattacharya, 2010). Many of these falls result in females seeking medical attention or requiring emergency services for maternal injury or fetal complications (Dunning, LeMasters, & Bhattacharya, 2010). As of 2010, falls were considered the most common cause of minor injuries correlated to hospital admissions in pregnant females (Dunning et al., 2010). While the cause of increased fall risks in this population remains unclear, several factors—such as rapid anthropometric and physiological adaptations to the female body—are commonly observed in preparation for childbirth.

Pregnancy typically lasts up to nine months or 39 to 40 weeks, which is broken down into three trimesters, averaging 13 weeks a trimester (Spong, 2013). Each trimester is characterized by an onset of accumulating changes that occur within the female body. The first trimester consists of internal and major hormonal changes as implantation of the embryo takes place (Centers for Disease Control and Prevention, 2019), causing the fewest external morphological changes to the female. The second trimester is marked by the onset of gestational mass gain anteriorly about the abdomen and increased hormone-induced ligament laxity (Talbot & Maclennan, 2016), thus beginning physical and locomotive adaptations. The third, and final, trimester has the greatest amount of physical changes such as mass gained, swelling of the limbs, muscle weakness, and cardiovascular strain, therefore correlating to the greatest evidence of mechanical changes. By the end of pregnancy, females are recommended to have gained an additional twenty-five percent of their prenatal body mass (Hagan & Wong, 2010). After birth, or during postpartum, the female body slowly reverts to prenatal state over the course of six months. With this considerable amount of time and rapidly accumulating growth throughout pregnancy, the female body must continuously mechanically adapt to ensure that functional movement is not impaired.

As gestational mass increases anteriorly, the concentrated mass shifts the body's center of mass (COM) shifts outside of the base of support (BOS) of the feet, thus creating postural instability (Whitcome, Shapiro, & Lieberman, 2007). In order to correct for imbalance, the spine curves into lumbar lordosis while consequently stressing the spine and muscles of the abdomen, back, and surrounding hip joints (Okanishi, Kito, Akiyama, & Yamamoto, 2012; Whitcome et al., 2007). These alterations, along with hormone-related swelling and ligament laxity, can also lead to increased pain and thus affect how a female moves while pregnant. Additionally, this increasing instability and correctional movement throughout pregnancy correlates to physical and mechanical adaptations to avoid falls or injury.

Postural stability has been quantified in a series of studies to examine how physical adaptations to pregnancy affect static posture. It has been noted that postural control decreases as pregnancy progresses, especially in the frontal plane, likely due to the unevenly distributed gestational mass (Danna-Dos-Santos et al., 2018). Pregnant females also relied heavily on increasing stance width and visual input for perceived and actual stability mediolaterally (Jang, Hsiao, & Hsiao-Wecksler, 2008). Even after birth, well into the postpartum period, females have displayed increased postural sway in several variables, thus illustrating a maintained decrease in balance (Opala-Berdzik et al., 2015). This lack of postural stability not only increases the perceived sense of falling but also creates a "cautious" approach to dynamic movement patterns (Gottschall, Sheehan, & Downs, 2013).

The gait of pregnant females is sometimes described as a "waddle" due to the sense of instability created by the gestational mass gain. As beforementioned, posture and balance are affected in the second and third trimester, making certain aspects of dynamic movement limited. Temporospatial aspects of gait are affected with advancing pregnancy, wherein double-limb support time increases, step length decreases, and velocity slows significantly, which are all characteristics of a "cautious" gait cycle, aimed at mitigating a fall (Gottschall et al., 2013). Consequently, some attempts to increase stability may also affect the normal loading and function of joints, such as asymmetrical joint loading (Branco et al., 2016), and thus creating an energy inefficient gait (McCrory, Chambers, Daftary, & Redfern, 2014b).

Considering the combination of decreased stability and altered gait patterns, stair locomotion tasks have become an increased concern. Stair locomotion is a task that not only requires increased stability on a single limb, but also challenges many populations with decreased balance, such as pregnant females and the elderly. In fact, nearly 40 percent of pregnant females reported falling while using stairs (Dunning et al., 2010). Previous research has examined the kinetics of stair locomotion, finding that increasing gestational mass increased AP breaking impulse, ML sway, and ML GRFs during stair locomotion tasks (McCrory, Chambers, Daftary, & Redfern, 2013), likely as a method to increase stability. Surprisingly little research has been done on advancing pregnancy on stair kinematics, creating a gap in the literature.

The purpose of this study was to examine postural control during bilateral (BL) single-limb support (SLS) conditions, as well as stair locomotion kinematics in healthy pregnant and postpartum females when compared to non-pregnant healthy females. Due to the physical adaptations of advancing pregnancy, it was hypothesized that females in the second and third trimesters would display decreased BL and SLS postural control during static standing. Furthermore, second and third trimester females were predicted to have altered stair kinematics compared to non-pregnant females during both ascent and descent of stairs.

Literature Review

I. Stages of Pregnancy

Pregnancy is considered the state of carrying an embryo or fetus within the female body (Centers for Disease Control and Prevention, 2019). The gestational period typically lasts up 39 to 40 weeks, which can be broken down into three trimesters, each consisting of 13 weeks on average (Talbot & Maclennan, 2016). The postpartum period follows after birth, which spans up to six months after delivery (Romano, Cacciatore, Giordano, & La Rosa, 2010). Each trimester is characterized by different adaptations to the female body, and therefore will be discussed separately at length.

First Trimester

The first trimester elicits the fewest external mechanical changes to the female body. Primary occurrences are internal changes related to ovulation and fertilization within the first two weeks, followed by implantation of the egg to the uterine wall within week three and four (Centers for Disease Control and Prevention, 2019). Females experience physical discomforts starting as early as week five to six of the first trimester, consisting of, but not limited to: nausea, vomiting, extreme fatigue, food cravings/aversion, mood swings, and body mass gain/loss (Di Renzo, Mattei, Gojnic, & Gerli, 2005). Some evidence suggests that postural adjustments may occur as early as the first trimester (Danna-Dos-Santos et al., 2018), or postural sway may increase due to temporary nausea (Yu, Chung, Hemingway, & Stoffregen, 2013), however most physical adaptations are not significantly different between non-pregnant and first trimester females. In fact, many biomechanical analyses comparing non-pregnant females to females in the first trimester lack significant differences in many functional movement patterns, therefore excluding first trimester participants from most pregnancy studies altogether (Gilleard, Crosbie, & Smith, 2008; Inanir, Cakmak, Hisim, & Demirturk, 2014).

Second Trimester

The second trimester typically marks the initial physical and locomotive adaptations, primarily as a result of drastic cumulative gestational mass gain occurring within this time. Nausea and fatigue begin to clear, but aches in the back, abdomen, thighs, and groin begin to manifest along with swelling in the ankles, fingers, and face (Centers for Disease Control and Prevention, 2019). As the abdominal area begins to gain mass anteriorly, normal walking speed and energy costs are negatively affected (Aguiar et al., 2015). Ankle and hip joints tend to become overloaded throughout the stance phase in the sagittal and frontal planes during the second trimester, likely due to the gain and distribution of the added mass, which can directly alter normal gait mechanics (Aguiar, Santos-Rocha, Branco, Vieira, & Veloso, 2014).

Third Trimester

The third trimester of pregnancy involves the most noticeable external changes to the female body. Adaptations from the second trimester continue to amplify into the third trimester. The combination of the added mass, hormonal changes, and ligament laxity correlate with cardiovascular and vascular changes, creating shortness of breath and increased swelling of the limbs (Talbot & Maclennan, 2016; Tan & Tan, 2013). The anteriorly concentrated gestational mass causes significant mechanical and postural disadvantages by shifting the center of mass (COM) outside of the base of support (BOS), which can lead to curvature of the spine, hindered abdominal strength, and anterior pelvic tilt (Whitcome et al., 2007). Females in the third trimester typically display movements lacking energy efficacy, such as relying on increased double-support time (Wu et al., 2002), altered joint loading mechanics for stability (Branco, Santos-Rocha, Vieira, Aguiar, & Veloso, 2015), and hindered joint range of motion (ROM) of the lower extremities during the gait cycle (Hagan & Wong, 2010).

Postpartum

While less biomechanically researched, the postpartum period also contains remnants of the mechanical restraints associated with pregnancy. Body mass, spinal curvature, and pelvic tilt slowly begin to revert to prenatal state; however, the process is not instantaneous (Romano et al., 2010). Furthermore, lactation may prolong the morphological effects of pregnancy, such as mass gained during pregnancy. While research focusing on the postpartum period reveals that postpartum females had similar gait patterns to non-pregnant females (Foti, Davids, & Bagley, 2000), the inclusion criteria to be considered a postpartum subject lacks consistency among the literature. Additionally, depending on the variables being examined, females can experience full reversion to prenatal conditions such as normal gait velocity, or alternatively, permanent damage to the musculoskeletal structure of the foot (Segal et al., 2013).

II. Physical Changes that May Contribute to Motor Changes

Females who become pregnant are at a disposition for physical changes that accumulate throughout gestation. As the fetus grows, more gradual physical changes occur to the female body. These physical changes can lead to altered movement patterns aimed to maintain stabilization when body mass distribution changes continuously throughout gestation. Ultimately motor function adaptations can result in an increased risk for tripping or falling during daily tasks, which may lead to injuries, or hospitalization of the female. These physical adaptations are broken down into more detail to correlate to the mechanical adaptations of the body.

Gestational Body Mass Gain

Gestational body mass gains occur from the growth of the fetus, placenta, amniotic fluid, and increasing uterine tissue, breast tissue, total body water, intracellular and extracellular water, and adipose tissue (Tan & Tan, 2013). According to the Institute of Medicine (2009), the recommended amount of mass gain for a female with a healthy pre-gestational body mass index (BMI) is between 11.5 to 16kg, and less for females who are overweight or obese. However, approximately forty-eight percent of females gain more than recommended during pregnancy (Centers for Disease Control and Prevention, 2019). This gradual increase in mass can alter the loading pattern on joints and have an effect on posture as lumbar lordosis increases and pregnancy progresses (Whitcome et al., 2007). Arguably since nearly half of all females gain more mass on average, they may be further susceptible to mechanical modifications and therefore be at higher risk of injuries. Outside of physical repercussions, females who become overweight or obese during pregnancy are also at an increased risk of developing other complications, such gestational diabetes, preeclampsia, eclampsia, and/or delivering a macrocosmic infant (an infant that is too heavy upon delivery) (Baeten, Bukusi, & Lambe, 2001).

Back and Pelvic Pain

Pregnancy-related Pelvic Pain (PRPP) occurs in approximately fifty percent of pregnant females (Wu et al., 2002). However, some females reported that the pain is not always localized to the pelvic region, but also occurs in the lumbar region of the back (Gutke, Östgaard, & Öberg, 2008). One theory suggests that PRPP is associated with increased joint laxity that manifests during pregnancy, with symptoms that continue into the postpartum period (Gutke et al., 2008). Additionally, females with asymmetrical sacroiliac joint laxity may have a higher incidence of

PRPP during pregnancy and postpartum stages than those with symmetrical sacroiliac joint laxity (Damen et al., 2002). Other studies suggest that pain is a result of poor muscle endurance in the back and pelvis, rather than insufficiency or relaxation of the joints (Norén, Östgaard, Johansson, & Östgaard, 2002). Regardless, pregnant females experiencing either localized, or combined pelvic and thoracic pain, have shown to have significantly slower walking speeds compared to their pain-free counterparts (Gutke et al., 2008; Norén et al., 2002).

Anterior Pelvic Tilt and Lumbar Lordosis

As previously mentioned, gestational mass occurs primarily in the abdomen, creating a disproportional stress to the spine. There are conflicting conclusions regarding lumbar lordosis, or an increase in the curvature of the spine, being present in later trimesters when gestational mass is greatest. One study reported that the lumbar spine flattened in pregnant females, meaning lumbar lordosis decreased, which may suggest that the transition of the spine may be more reliant on the female's posture prior to childbearing rather than following a specific trend (Okanishi et al., 2012). While others fault all differences such as anterior tilt of the pelvis and weakened abdominal muscles to be directly related to increasing lumbar lordosis (Norén et al., 2002). Foti et al. (2000) revealed that not all females had lumbar lordosis, but females who had greater anterior pelvic tilt also had greater lumbar lordosis. This may be a result of previous study and statistical designs, as many pregnancy studies are cohort studies rather than longitudinal and specific to each female.

Center of Mass Alterations

Humans are locomotor bipeds with the center of mass (COM) is typically oriented above the supporting hip joints, and within the BOS of the feet for maximum stability (Whitcome et al., 2007). As mass increases anteriorly in the later trimesters, the COM shifts anteriorly as well, creating postural instability and increased torque about the hip joints (Whitcome et al., 2007). While the most prominent alterations occur anteriorly, it is important to note that the increasing mass of the limbs and breasts can also contribute to the shifting COM, and therefore the increase in lower trunk moment of inertia as well (Jensen, Doucet, & Treitz, 1996). When considering the lumbar lordosis theory, the lower back extends to realign the COM over the hips and base of support and thus maintaining evenly distributed balance (Whitcome et al., 2007). These changes have appeared to not only affect females undergoing advancing pregnancy, but carry on into the early postpartum period as well (Catena, Campbell, Wolcott, & Rothwell, 2019). Unfortunately, COM research in pregnant females remains a novel subject. Due to the uniqueness of gestational mass gain and its uneven distribution, there are incongruities on COM models for this population. Recent research has attempted to quantify the approach for COM in pregnant females, however much of the research regarding COM alterations are still heavily theoretical.

Ligament Laxity

Ligament laxity, or relaxation of the joints, has been theorized to aid in vaginal delivery by decreasing the rigidity of the pelvic joints (Marnach et al., 2003). Increased ligament laxity can also allow compensation for the expansion of the lower rib cage, in an attempt to salvage functional residual capacity of the lungs, which is decreased by the impact the fetus has on the diaphragm of the female (Talbot & Maclennan, 2016). This diaphragmatic elevation occurs noticeably in the third trimester, and may increase the feeling of breathlessness without hypoxia (Talbot & Maclennan, 2016). Evidence suggests that generalized joint laxity can increase from one pregnancy to those thereafter, with the maximum amount typically occurring in the second pregnancy (Calguneri, Bird, & Wright, 1982). While an increase in ligament laxity may aid in birth, it can have negative repercussions on the surrounding muscles and increase the likelihood of pain during pregnancy.

Muscle Weakness

With cumulative gain in body mass and ligament laxity, the muscles become more fatigued with advancing pregnancy. When strength between abdominal muscles and back extensor muscles become imbalanced, lumbar lordosis presents itself in non-pregnant individuals, which typically increases the likelihood of back pain (Kim et al., 2006). This is more significant for pregnant females because the increased anterior load on the spine and increased strain on the back and pelvic joints may fatigue the abdominal muscles, which counteract the instability of the offset COM (Norén et al., 2002). Maintaining an upright posture increased energy cost and led to fatigued muscles in both the abdominal walls and back extensors in pregnant individuals (Gilleard, Crosbie, & Smith, 2002). Furthermore, the muscles in the pelvis and hips are increasingly loaded from gestational body mass gain, and therefore tend to be weakened as well, which may correlate to altered joint loading mechanics (Foti et al., 2000).

Changes to the Foot

Pregnant females commonly need to increase in shoe size by the third trimester to accommodate for pregnancy-related changes to the feet (Segal et al., 2013). Foot length, width, and volume typically increase during pregnancy, although the reasons remain unclear (Segal et al., 2013). Edema and ligament laxity have both been debated as the cause for increasing foot size with pregnancy (Alvarez, Stokes, Asprinio, Trevino, & Braun, 1988). More specifically, foot arch height may decrease as a consequence of ligament laxity and ligament shortening created by the center of pressure is shifting to the posterior part of the foot to accommodate for anterior gain in mass (Segal et al., 2013). Interestingly, these drastic changes to the foot have shown to be irreversible in some females—especially multigravida females—and may increase risk of lower limb musculoskeletal problems later in life (Segal et al., 2013). These alterations are often associated with increased pain in the feet and can hinder normal walking and stair locomotion as regional pressure on the foot can cause pain but is also important when shifting weight down stairs (Rao, Baumhauer, Tome, & Nawoczenski, 2009), which is important because pain may relate to altered movement and further raise the concern of becoming injured. Interestingly, swelling and/or pain in the feet correlated with increased floor contact time and slower walking speeds in pregnant females (Goldberg, Besser, & Selby-Silverstein, 2001), although this may be a combination of the other changes taking place during pregnancy as well.

Hormones and Swelling of the Limbs

Hormones commonly associated with pregnancy include cortisol, estradiol, progesterone, and relaxin which together may be responsible for increased joint laxity during pregnancy and the postpartum period (Talbot & Maclennan, 2016). There is a disagreement within the literature regarding which hormones are specifically responsible for ligament laxity. Some research suggests higher levels of relaxin and estrogen contribute to ligament laxity of the pelvis, while others found that estradiol and progesterone to be higher in females who reported higher incidences of joint pain, which is believed to be a result of ligament laxity (Marnach et al., 2003). This suggests that the hormonal level combinations may be more responsible for joint laxity rather than level of hormonal presence alone.

Peripheral edema or water retention in interstitial space of the lower limbs can cause unpleasant walking conditions for females in their second and third trimester (Hartmann & Huch, 2005). Hormone changes, increased venous pressure, postural changes, and the mass of the fetus compressing the iliac and femoral veins can collectively contribute to an increase in venous volume and vascular inefficiency in the lower limbs, thus resulting in edema or swelling of the legs and feet (Rabhi et al., 2000; Soma-Pillay, Nelson-Piercy, Tolppanen, & Mebazaa, 2016). Females have reported most of the edema related discomforts occurring during heel strike, which could affect normal gait patterns. Vascular smooth muscle and respiratory smooth muscle relaxation are also attributed to increased levels of progesterone, increasing cardiac output and respiratory rate, respectively (Talbot & Maclennan, 2016). Cardiac output and systemic vascular resistance are directly related to mean arterial blood pressure, which increases until full term pregnancy. While overall blood pressure is typically maintained throughout pregnancy (Tan & Tan, 2013), the alterations to the cardiovascular system can also cause some unfavorable side effects, such as swelling in the limbs.

III. Motor Adaptations

Postural Control and Balance

Postural control, or balance, can be measured by quantifying how much a participant sways over a period of static standing. Balance can be recorded with center of pressure excursion (COPE) data from force platforms. Common postural control analyses take sway length, sway velocity, sway path, and sway area into consideration of balance (Roerdink, Hlavackova, & Vuillerme, 2011). Posturograms created from the standard deviation of the anteroposterior or mediolateral sway to create a COPE area are also considered reliable representation of postural control (Harringe, Halvorsen, Renström, & Werner, 2008).

Postural changes occur with progressing pregnancy, but it varies between females. Some studies revealed that while in the seated position, the increased abdominal size in relation to the thighs caused the pelvis to rotate posteriorly and thoracolumbar spine to increase in flexion

(Gilleard et al., 2002). This may lead to strain or back injury, as it hinders the natural ability to relocate the static compressive load on the spine when sitting (Gilleard et al., 2002). Similarly to sitting posture, females have an individualized postural response to the added mass of pregnancy while standing. Increased postural sway and decline in standing balance performance have typically been recorded in the later stages of pregnancy and up to eight weeks postpartum (Catena et al., 2019). Across the literature, posture in nulliparous (non-pregnant) females compares to females in the first trimester, justifying the reasoning behind not including first trimester females to pregnancy research studies. However, one cross-sectional study speculated that COPE greatly increased in the first trimester and then remained similar across pregnancy (Danna-Dos-Santos et al., 2018). Arguably this is a result of differences in study designs, as most research regards postural sway to be individualized to the participant. Interestingly some postural sway was observed in the first trimester as a result of morning sickness, but this was a temporary condition which was corrected for with a wider stance to increase stabilization, and lowered the cause of concern in first trimester females (Yu et al., 2013).

In theory, postural sway in pregnant females correlates with the advancing stages of pregnancy and the increase in anterior mass altering the pre-pregnancy COM (Whitcome et al., 2007). However, reported results varied on the directional sway pattern during static standing trials. Some pregnant females increase in anteroposterior (AP) sway (Danna-Dos-Santos et al., 2018), while others increased in mediolateral (ML) sway directions (Jang et al., 2008). Discrepancies in balance assessment techniques may be the reason for the differences. Most studies found that third trimester females naturally tend to increase their stance width, therefore increasing their base of support and improving their perceived sense of balance as well as their stability in the mediolateral directions (Jang et al., 2008). Although, this could also be a consequence of the pelvis widening in preparation for childbirth, and not a selected stance width alone. With the eyes closed, the mediolateral sway significantly increased in the third trimester, suggesting that pregnant females rely heavily on visual cues for balance (Jang et al., 2008).

Sit-to-Stand

Sit-to-Stand or Stand-to-Sit are two types of functionality tested used in clinical settings to evaluate coordination (Catena, Bailey, Campbell, & Music, 2019; Lou et al., 2001). Pregnancy can have an impact on performance in both tasks and may lead to a fall if executed poorly, and therefore is correlated to pregnant females lacking coordination. Catena et al. (2019) concluded that pregnancy-related decreases in sagittal plane hip ROM altered the coordination of females during stand-to-sit movements. Limited hip flexion was associated with the increased knee moment, therefore making the task more difficult, especially when the chair height was shorter than the lower limb height of the participant (Lou et al., 2001). Pregnant females were also found to require more time during sitting and standing tasks, with some requiring the assistance of a handrail when rising from lower chair heights (Takeda, Katsuhira, & Takano, 2009).

Gait Kinematics

Pregnant females oftentimes have an observable “waddling” gait pattern, especially later into the third trimester of gestation. This movement pattern has also been termed as a “cautious” gait strategy, characterized by increased step width, reduced speed, and decreased single-limb support time (Gottschall et al., 2013). Some evidence supports that pregnant females adapt their gait by increasing the step width in order to maximize stability and control mediolateral motion during the stance phase of walking (Lymbery & Gilleard, 2005), which is a common tactic used by obese populations as well (Spyropoulos, Pisciotta, Pavlou, Cairns, & Simon, 1991). Consequently, some studies found that a wider step width could contribute to the increases in hip adduction moment observed in pregnant females compared to non-pregnant controls, as well as decrease of energy efficiency during gait (McCrory, Chambers, Daftary, & Redfern, 2010). However, others theorized that the increased pelvic width was compensated with hip adduction during single leg support in order to keep the foot centered under the body, and thus decrease the need for an energy-inefficient waddle (Foti et al., 2000). Lastly, most studies agree that pregnant females decreased single support time by increasing their double support time and by decreasing their step length, which is a tactic commonly seen in the elderly population (Carpes, Griebeler, Kleinpaul, Mann, & Mota, 2008). While these tactics may be energy inefficient, they simultaneously increase stability and therefore create a sense of security regarding falling. In fact, females who had fallen during pregnancy displayed significantly slower walking speeds than those of pregnant females who had not fallen, strengthening the assumption that the reduction in speed is related to a sense of increased stability (McCrory, Chambers, Daftary, & Redfern, 2011).

Pregnancy may alter gait kinematics at the hip, knee, and ankle joints of the lower limbs. Primarily the combination of body mass gain and joint laxity contribute to the overuse of lower limb joints and therefore create altered joint movement patterns (Foti et al., 2000). As the supporting hip joints are overloaded and the pelvis tilts anteriorly, increased hip flexion, adduction, and extension occur and therefore external hip flexor moment increases (Aguiar et al., 2015; Foti et al., 2000). Pregnant females with especially higher body compositions have greater load effects on the hip joints in the sagittal and transverse plane (Branco et al., 2016). With one joint function being altered, the joints below are also affected. Knee flexion range of motion significantly increased in multiple studies (Aguiar et al., 2014; Branco et al., 2016), but there was little indication of cause. In some females, knee flexion was increased asymmetrical between limbs (Branco et al., 2016), while others displayed increased knee extension and greater hip adduction moment of force during swing and stance phase of gait (Aguiar et al., 2014). Additionally by the second trimester the hip flexors and knee extensors have decreased joint moments, meaning the joints have decreased absorption of mechanical energy and further contributing to the loss of dorsiflexion ROM in both pregnant and three month postpartum individuals (Foti et al., 2000). The exact reason for dorsiflexion being hindered is still unknown, but it may be from the added plantarflexor muscle activity compensating the mass increase (Hagan & Wong, 2010) or possibly in correlation to joint laxity and wider stance overloading the joint (Aguiar et al., 2014). Gottschall et al. (2013) mentioned that another common tactic to avoid falling includes increasing ankle dorsiflexion to increase toe clearance. Thus, if pregnant females have a decreased dorsiflexion capability, then they may be at greater risk for tripping or falling. It may also raise more concern for females who gain more body mass outside of what is considered healthy as it hinders joint ROM further.

Gait Kinetics

Despite the added gestational mass and joint kinematic alterations, few significant differences to peak values of vertical or anteroposterior components of GRF patterns were found between non-pregnant females and pregnant females (Branco et al., 2015; Lymbery & Gilleard, 2005) nor in pregnant females who had recently fallen (McCrory et al., 2010). However, significant increases to mediolateral GRF were found in late pregnancy when compared to the postpartum period (McCrory et al., 2011). Interestingly, some pregnant females displayed a greater medial GRF in the left lower limb during the loading response phase, meaning they maintained the medial force during the majority of the stance phase in a single limb—likely to compensate for imbalances when shifting from one foot to the next (Branco, Santos-Rocha, Aguiar, Vieira, & Veloso, 2016).

IV. Risks of Falling and Incidence Rates

Pregnant females fall at rates similar to the elderly population, making falls the most common form of minor injury that can lead to hospitalization (Dunning et al., 2010). Falls are the second most common reason for females to receive emergency medical attention after car accidents (Dunning et al., 2003). The incidence of falls is highest in the second trimester, which may be a result of the onset of gestational mass gain occurring in this trimester or due to females drastically decreasing activity in the third trimester (Dunning et al., 2010). Surprisingly more females under the age of 35 had a higher fall rate, which was theorized to be a result of younger females being more active than older females while pregnant (Dunning et al., 2003). Females have reported falling while performing daily functional tasks indoors (56%) and/or while using stairs (39%), with the two not necessarily being exclusive (Dunning et al., 2010).

V. Stair Locomotion

Stair locomotion is a challenging functional task for many movement impaired populations. Not surprisingly, nearly 40 percent of pregnant females reported falling while using stairs (Dunning et al., 2010). Budding research in stair locomotion revealed that pregnant females both ascend and descend stairs at a similar resultant velocities when compared to non-pregnant females (McCrory, Chambers, Daftary, & Redfern, 2014a). Surprisingly, females who reported falling during pregnancy also had similar velocities on stairs than pregnant non-fallers as well, but reported falling while descending stairs (McCrory et al., 2014a). It was also previously reported that increased gestational mass gain was associated with an increased AP breaking impulse, increased ML sway, and increased ML GRFs during stair locomotion tasks

(McCrory et al., 2013), making the second and third trimesters of pregnancy more challenging while using stairs.

Surprising little research has been done to examine kinematics during stair locomotion in pregnant and postpartum females. During stair descent, gait and stair locomotion patterns are noted to have similarities in the stance and swing phases being at roughly 60 and 40 percent of the gait cycle, respectively (Livingston, Stevenson, & Olney, 1991). However, during stair ascent, stance has shown to vary from 50 to 60 percent and swing to vary from 40 to 50 percent (Livingston et al., 1991). Furthermore, joint ROMs of the lower extremities will differ significantly compared to gait when navigating stairs. When considering stairs of different step heights, the knee joint is theorized to act as the primary compensator of joint ROM (varying between <90 to 105 degrees difference depending on step height), with the hip and ankle acting as secondary compensators (Livingston et al., 1991). Considering females who are pregnant have shown limited joint ROM during gait, it stands to reason that impairments may occur when utilizing stairs as well, and thus increase the risk of falls. A single study attempted to simulate pregnancy conditions in females in order to compare joint kinematics to non-pregnant females, and found that anterior load correlated to greater plantarflexion, knee flexion, and lumbar angle during ascent and greater plantarflexion, knee flexion, and hip flexion during descent (Masad, Almashaqbeh, Smadi, Abu Olaim, & Obeid, 2019). However, no known studies have measured joint kinematics in pregnant and postpartum females up to date.

Methods

Participants

An *a priori* power analysis (G*Power v3.1.9.2, Dusseldorf, Germany) was performed on hip flexion data from Foti et al. (2000). Based on a proposed effect size of 1.25, power of 0.8, and alpha of (0.05), 36 total participants (9 per group) were required to achieve adequate statistical power. Eighteen females between the ages of 18-34 years, consisting of six non-pregnant controls (NP), five 2nd trimester (2T), four 3rd trimester (3T), and three postpartum (POST), were recruited for participation in this study. Participant anthropometrics are presented in Table 1**.** In order to be included in the study, all participants were required to be free of lower limb injuries. Participants were excluded if they were considered a "high-risk" pregnancy by their physician, which can be related to a chronic health issue or a complication that puts either the female or fetus at risk during pregnancy or birth (National Institutes of Health, 2017). Females who were in the postpartum group had to be no more than six months postpartum. The study was approved by the University of Texas at El Paso's IRB and written consent was obtained from all participants prior to conducting any laboratory activities.

Table 1 Anthropometric means and standard deviations for females in the non-pregnant, 2nd trimester, 3rd trimester, and postpartum groups.

	N	Age (years)	Height (m)	Mass (kg)
Non-pregnant, controls	6	24.0 ± 1.8	1.59 ± 0.05	64.7 ± 9.2
2nd trimester	5	25.6 ± 4.7	1.64 ± 0.06	76.3 ± 11.9
3rd trimester	4	25.3 ± 4.2	1.65 ± 0.05	85.7 ± 19.2
Postpartum	3	28.0 ± 2.2	1.57 ± 0.05	76.1 ± 14.7

Experimental Procedure

Data collection took place in the *Stanley E. Fulton Gait Research & Movement Analysis Lab* at the University of Texas at El Paso. Participants wore tight-fitting clothing for accurate segment representation and were instructed to perform all tasks while barefoot. Retroreflective spherical markers were adhered to the following anatomical landmarks: bilaterally, with hypoallergenic double-sided adhesive tape: acromion processes, anterior superior iliac spines, posterior superior iliac spines, iliac crests, greater trochanters, lateral and medial epicondyles, lateral and medial malleoli. Single markers were used on the following anatomical landmarks to aid in segmental tracking: manubrium, sternal process, seventh cervical vertebrae, tenth thoracic vertebrae, inferior angle of the right scapula, sacrum and the base of the second toe. To assist in tracking lower extremity movement, thermo-plastic shells with four non-collinear markers were placed bilaterally, mid-segment, on the thighs and legs using elastic wraps. Lastly, three non-collinear maker clusters were placed bilaterally over the calcaneus.

Marker trajectories were captured using a 10-camera three-dimensional motion capture system (200 Hz, Vicon Motion Systems, Ltd., Oxford, UK). Kinetic data were obtained with in-ground force platforms (1,000 Hz, Advanced Mechanical Technology Inc., MA, USA), which were mounted flush with the floor.

Balance was tested in three separate conditions, for 30 second intervals, with eyes open in each condition: 1) bilateral standing (BL); 2) on the left limb only; and 3) on the right limb only. During all balance trials, participants were instructed to stand quietly on a single force platform, with the arms held over the stomach and eyes looking straight ahead. While previous research has been conducted with eyes closed to mitigate environmental effects on balance, the concern for safety was the main reasoning for having the participants remain with eyes open, as pregnant females were found to rely heavily on visual cues to maintain postural control (Butler, Colón, Druzen, & Rose, 2006). Participants were then assessed for single-limb support (SLS) by balancing on each limb in the middle of a single force platform for a total of thirty seconds.

Laboratory personnel spotted participants while performing the single-leg tasks to reduce the risk of falling.

For stair locomotion trials, the staircase consisted of four steps (1m minimum width, riser height of 0.20m maximum, tread depth of 0.25m minimum) an extended platform at the top, and an attached unilateral handrail. Participants walked at a self-selected pace across three meters over ground, striking the force platform prior to ascending the stairs. Once participants reached the top of the stairs, they were instructed to turn around and descend the stairs at their own pace and walk the remaining 3m back to the starting position. Participants were instructed to avoid the use of the handrail unless they felt that they were about to lose their balance or fall. Data collection was completed once ten successful ascent and descent trials were recorded.

Data Processing

Center of pressure coordinate data were exported from Vicon Nexus and imported into MATLAB to be filtered at 12.5 Hz, based on previous research (Callahan, 2017). Posturograms were created during quiet standing trials both in BL and SLS conditions by the center of pressure excursion area (COPEa). COPEa was defined by the absolute maximum and minimum medial-lateral (X) and anterior/posterior (Y) coordinate data from the equation: $COPE_a = (X_{max} - X_{min}) \times (Y_{max} - Y_{min})$ in mm^2 (Callahan, 2017). COPEa variables consisted of bilateral (BCOPEa), right limb balance (RCOPEa), and left limb balance (LCOPEa) conditions.

All raw kinematic variables were exported from Vicon Nexus and computed in Visual 3D software (C-Motion, Inc., Germantown, MD, USA) and filtered with low-pass Butterworth digital filters at cutoff frequencies of 6 Hz. An eight-segment model was constructed from marker trajectories, including the trunk, pelvis, left and right thigh, leg, and foot segments. From the smoothed trajectories, sagittal plane range of motion (ROM) at the ankle and knee joints, stance width, and sacral marker velocity were computed using a Cardan (X,Y,Z) rotation sequence. Sagittal ankle and knee ROMs were measured during stair trails from heel strike to heel strike in the limb that struck the force platform in both ascent and descent. Heel strike was measured as foot contact with the initial stair followed by the foot contact made with the same limb at the third step. Stance width was measured during stair trials as the width between both feet during double limb support phases. Stair locomotion velocity during ascent/descent was computed as the first derivative of sacral marker position in all three planes of motion (sagittal, frontal, and transverse). Mean sacral velocities were then exported to Microsoft Excel to compute resultant velocity, using the Pythagorean Theorem.

Statistical Analysis

Statistical analyses were conducted using SPSS 24 (IBM, NY), with all mean and standard deviations being determined for each variable. An independent one-way ANOVAs (α=0.05) were utilized to compare both subject height and mass among groups (NP, 2T, 3T, POST). If a significant difference was detected in the omnibus ANOVA test, pairwise comparisons were interpreted after applying the Sidak adjustment.

A three (variable: $BCOPE_a$, $RCOPE_a$, $LCOPE_a$) by four (group: NON, 2T, 3T, POST) factorial analysis of variance (ANOVA; α=0.05) was used to test for statistical significance for $COPE_a$. If an interaction was detected, a one-way ANOVA with Sidak adjustments were used for each variable and group, respectively. If no interaction was detected, variable and group main effects were examined after applying the Sidak adjustment.

Independent one-way ANOVAs (α=0.05) were utilized to test for statistical significance during stair ascent and descent in the following variables: stance width, knee ROM, ankle ROM, and velocity components. When a significant difference was detected in the omnibus ANOVA test, pairwise comparisons were interpreted after applying the Sidak adjustment.

Results

Participants

One-way ANOVA results revealed no significant differences among the groups in age – F(3, 17)=1.17; *p*=0.36; height—F(3,17)=0.59, *p*=0.24 ; nor mass—F(3, 17)=1.92, *p*=0.17.

COPEa Variables

COPEa ANOVA results revealed that there was not a significant group by condition interaction (F(6, 39)=0.43, *p*=0.85, $\eta^2 = 0.06$), nor was there a group main effect (F(3,39)=0.10, *p*=0.96, $\eta^2 = 0.01$), however there was a condition main effect (F(2,39)=31.8, *p*<0.001, $\eta^2 = 0.62$). Bilateral COPEa was significantly greater compared to SLS on the left (*p*<0.001) and right (*p*<0.001) limbs, but right and left limbs were not significantly different form each other (*p*=0.58); **Figure 1.**

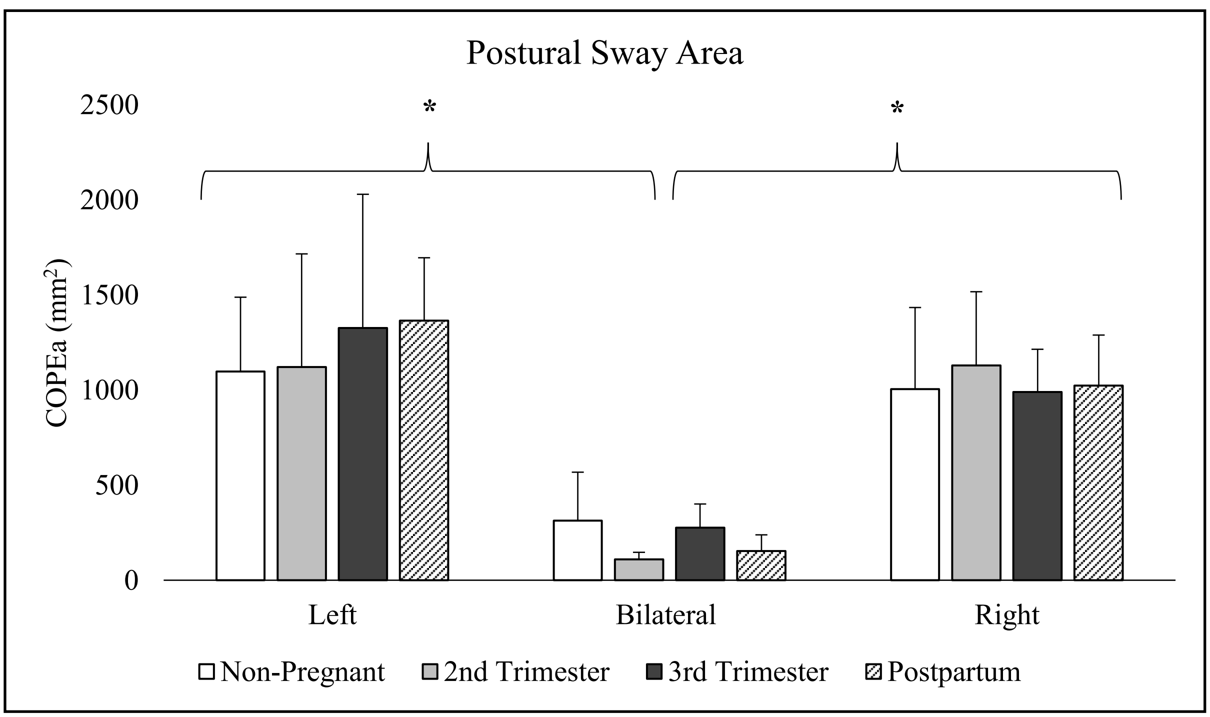

Figure 1. Means and standard deviations for COPEa by standing condition (left limb, bilateral, right limb) among groups.
* indicates *p* < 0.001 for Left vs. Bilateral and Right vs. Bilateral.

Stair Kinematics

Independent one-way ANOVA results for each variable revealed no significant differences among groups during stair ascent: ankle ROM – $F(3, 5) = 2.86$, $p=0.14$; knee ROM – $F(3, 5) = 1.37$, $p=0.35$; stance width – $F(3, 5) = 0.23$, $p=0.87$; ML velocity– $F(3, 5) = 0.51$, $p=0.69$); AP velocity – $F(3, 5) = 1.68$, $p=0.29$; vertical velocity – $F(3, 5) = 1.81$, $p=0.26$; and resultant velocity – $F(3, 5) = 1.64$, $p=0.29$). Nor was there significance among groups during stair descent: ankle ROM – $F(3, 5) = 0.69$, $p=0.60$; knee ROM – $F(3, 5) = 2.07$, $p=0.22$; stance width – $F(3, 5) = 2.36$, $p=0.19$; sagittal velocity – $F(3, 5) = 2.94$, $p=0.14$; frontal velocity – $F(3, 5) = 1.63$, $p=0.29$; transverse velocity – $F(3, 5) = 0.46$, $p=0.72$; and resultant velocity – $F(3, 5) = 2.05$, $p=0.23$). **Table 2** displays the means and standard deviations for all kinematic variables between groups.

Table 2. Means and standard deviation values for kinematic variables among groups.

		Non-Pregnant	**2nd Trimester**	**3rd Trimester**	**Postpartum**
	Ankle ROM (deg)	32.99 ± 6.63	32.78 ± 3.50	19.01 ± 3.74	44.18 ± 16.03
	Knee ROM (deg)	86.43 ± 3.63	92.24 ± 1.57	85.95 ± 4.61	90.54 ± 5.06
	Stance Width (m)	0.10 ± 0.03	0.11 ± 0.00	0.12 ± 0.02	0.10 ± 0.02
Ascent	ML Velocity (m/s)	0.01 ± 0.00	0.02 ± 0.00	0.02 ± 0.02	0.01 ± 0.01
	AP Velocity (m/s)	0.72 ± 0.10	0.62 ± 0.04	0.75 ± 0.05	0.60 ± 0.10
	Vertical Velocity (m/s)	0.28 ± 0.04	0.25 ± 0.02	0.26 ± 0.01	0.22 ± 0.02
	Resultant Velocity (m/s)	0.77 ± 0.11	0.67 ± 0.04	0.79 ± 0.05	0.64 ± 0.10
	Ankle ROM (deg)	47.56 ± 16.00	39.73 ± 8.51	38.18 ± 1.34	65.08 ± 40.15
	Knee ROM (deg)	93.97 ± 7.04	99.04 ± 1.06	95.24 ± 2.18	104.01 ± 2.32
	Stance Width	0.13 ± 0.03	0.07 ± 0.03	0.13 ± 0.03	0.13 ± 0.01
Descent	ML Velocity (m/s)	0.02 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.07 ± 0.05
	AP Velocity (m/s)	0.68 ± 0.03	0.63 ± 0.06	0.71 ± 0.11	0.33 ± 0.43
	Vertical Velocity (m/s)	0.68 ± 0.03	0.63 ± 0.06	0.70 ± 0.11	0.33 ± 0.43
	Resultant Velocity (m/s)	0.79 ± 0.03	0.72 ± 0.05	0.81 ± 0.13	0.64 ± 0.09

ML = mediolateral, AP = anteroposterior

Discussion

The purpose of this study was to examine possible adaptations to balance among pregnant and postpartum females when compared to non-pregnant females. It was hypothesized that second and third trimester females would display increased COPEa in BL and SLS conditions and altered stair locomotion kinematics when compared to non-pregnant females. The current study found no changes to BL or SLS balance conditions among groups, and right and left limb conditions were similar across groups, suggesting that static SLS balance remains even between limbs throughout advanced pregnancy and postpartum. Additionally, joint ROMs, stance width, and velocity components were not found to be significantly different compared to non-pregnant females in this study.

The balance results from the current study are not aligned with results from previous studies, which indicated that females in the third trimester had greater sway results during static standing trials. Some studies agree that pregnant females were found to have increased AP directional sway (Jang et al., 2008; Oliveira, Vieira, Macedo, Simpson, & Nadal, 2009), while this study examined sway area as a whole, rather than comparing directional sway. Furthermore, stance width has been shown to alter sway variables in pregnant females as increasing or decreasing BOS relates to a sense of stability (Nagai et al., 2009), whereas this study utilized a standard stance width to note any changes between subjects. Furthermore, subjects were not perturbed during balance trials by way of intentionally narrowing stance width or removing visual input (Butler et al., 2006). SLS had not yet been measured in pregnant and postpartum females, despite SLS being a clinical tool to assess for fall risk in high-risk populations (Hurvitz, Richardson, Werner, Ruhl, & Dixon, 2000). While SLS outcomes were significantly smaller than BL outcomes, they were not significantly different when comparing among groups. Additionally, left and right limb balance remaining symmetrical throughout pregnancy did not support the hypothesis of the current study. Asymmetrical results were anticipated based on previous findings of significant joint laxity imbalances between the right and left sacroiliac joints (Damen et al., 2001), and uneven joint moments between the left and right limb during the loading response of gait (Branco et al., 2016) in third trimester females. However, the association between SLS and higher fall risks may only apply to those who are movement impaired, whereas the current study only recruited healthy females with possible pregnancy-related movement constraints. This could also suggest that although previous studies found asymmetrical occurrence between limbs, the current study did not, and therefore pregnant females without asymmetry may not be at higher risk of falling.

Lower extremity joint ROMs were predicted to be altered mainly due altered joint ROMs in previous gait research, as well as joint ROMs being altered in stair kinematics of participants under simulated-pregnancy conditions (Masad et al., 2019). Preceding gait studies found that ankle ROM decreased into the third trimester (Foti et al., 2000; Hagan & Wong, 2010), which was mirrored—although not significantly—on average in third trimester females during stair ascent and descent of this study. The main concern behind possible decreased ankle ROM when considering stair tasks, is the amount of ankle ROM needs increase in order to descend stairs safely in healthy populations (Livingston et al., 1991), however this was not found to occur in the current study. Additionally no differences in knee ROMs were found to occur among groups, but knee ROM has been noted to be the most variable among stair studies (Andriacchi, Andersson, Fermier, Stern, & Galante, 1980; Livingston et al., 1991). Unlike the previous study that examined stair kinematics, the additional gestational mass did not cause participants to be significantly different in mass, which may have been the reason for lack of differences in joint

ROMs for this study. It is also worth mentioning that lack of significance in ankle and knee ROM may also have been a result of amount of foot contact with the stair being used (forefront vs full-foot) as it correlates to the amount of joint ROM needed in stair locomotion (Livingston et al., 1991).

Stance width was predicted to increase in the pregnant groups during stair locomotion, however, this was not reflected in the results. During gait, stance width increased significantly into the third trimester during in order to increase stability (Foti et al., 2000; Lymbery & Gilleard, 2005). However, this pattern was not observed during stair trials of the current study, although stance width did increase slightly on stair ascent. Stair descent step width was even among the groups, which may be due to descent requiring less mechanical effort and none of the participants anticipating a fall.

To the researchers' knowledge, this is the first study that measured all velocity components; previous studies only examined horizontal and vertical resultant velocities(McCrory et al., 2013; McCrory et al., 2014a). It was hypothesized that velocity would decrease primarily in the frontal and transverse components into the second and third trimester, based on gait findings, however the results did not reveal this. Unlike the current study, previous studies found that increase in gestational mass gain was frequently attributed to decreased gait velocity (McCrory et al., 2011), which was a trend expected to carry over to stair locomotion. However, similarly to other studies (McCrory et al., 2013; McCrory et al., 2014a), this study had no indication of pregnancy relating to decreased velocity in any direction. The reason for this may be that the participants were not significantly different among groups in mass, therefore not creating the correlation between increased mass and decreased velocity. Interestingly, pregnant females who fell during stair tasks, all reported doing so while descending stairs (McCrory et al., 2014b). It should be noted that while not significant, on average females in the third trimester actually increased their velocity in all directions during ascent and in AP and resultant velocity during descent. This was surprising and contradicts the theory that females will decrease velocity as a precaution to falling.

Thus, the current study found that consistent balance among non-pregnant, pregnant, and postpartum groups related to similarities in stair performance. It can be inferred that symmetrical balance, and consistent postural control throughout advancing pregnancy can relate to non-pregnant conditions of stair locomotion. Furthermore, significant gain gestational mass may play a large role in the likelihood of finding discrepancies within this population, as the current study had similar anthropometric measures among groups.

Conclusion

The purpose of the current study was to examine possible differences related to advancing pregnancy on balance and stair locomotion that may relate to increased fall risks. The females in this study were not found to be significantly different from each other in despite pregnancy and postpartum stages. Unlike previous studies, this study compared right and left limb balance, finding that pregnant females had symmetrical balance results between limbs. As these participants did not display increased risk factors or "cautious" movement patterns while performing stair tasks, it may be useful to incorporate SLS measurements as an assessment for fall risks in this population. Future studies may want to examine perceived and actual sense of stability when performing both balance and stair tasks to gain a more comprehensive understanding of stair tasks.

Limitations

The current study recognizes that the small sample size of participants may have interfered with possible significant findings. While discouraged, some participants felt the need to rely on the handrail for safety, which could have skewed stair locomotion results. The stair set used was up to standard building codes, however it should be noted that not all stair dimensions are similar in daily activities, thus making these results only applicable to similar stair dimensions. The ratio of height to step was also not taken into consideration, which has been shown to alter joint kinematics in stair tasks (however, our participants were not significantly different in terms of height). Additionally, the study may have been optimized if a longitudinal approach could have been utilized, however repeat visits and participant adherence is especially challenging in this population.

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Vita

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Thus far, Ms. Vanderhoof has presented two podium presentations at external conferences, one at the international level. In February 2020, she was awarded the Master's Award from OptiTrack during the Mid-South Biomechanics Conference in Memphis, TN, for her presentation on *Advancing Stages of Pregnancy on Postural Sway Area in Healthy Females*.

She acted as co-author on several abstracts, ranging in different populations of interest in the field of Biomechanics. Currently one manuscript she co-authored is in the process of publication titled *Live animation biofeedback does not induce motor pattern alterations in children with autism*.

Currently she has two years of experience as a Teacher's Assistant in the laboratory section of the undergraduate Biomechanics course and has mentored two colleagues during their time as Teacher's Assistants to the same program.

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