Effects of a Single Shift of Occupational Childcare on Knee Mechanics during Gait

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners. I understand that my thesis may be made electronically available to the public.

Abstract

The current literature shows that there are ergonomic challenges in occupational childcare, such as inappropriate heights of furniture for adults, and that childcare educators engage in high knee flexion positions beyond levels that have been previously associated with an increased risk of developing knee osteoarthritis. However, what has not yet been investigated is the possibility that childcare educators' knee mechanics during everyday activities, such as walking, differ after their shift, likely as a result of their daily work activities and work environment. This study aimed to evaluate the differences in childcare educators' knee kinematics and kinetics before and after their workday, in gait measures that, when compared to controls, have been associated with knee joint injury and disease, including knee flexion angle at heel strike, peak knee adduction angle, peak knee flexion moment, and peak knee adduction moment during gait. For this study, 21 childcare educators were recruited from early learning centres in the Waterloo/Wellesley areas. In their place of work, before (baseline) and after their workday, each participant completed walking trials until three successful trials, defined as their entire foot contacting the first force plate and the heel of the same foot contacting a second force plate in the same gait cycle, were obtained for each leg. Motion data and ground reaction forces were collected using markerless motion capture cameras and force plates, respectively. Two-tailed paired samples t-tests were run to evaluate changes in all outcome variables for both legs, except for peak adduction moment on the non-dominant leg, which was evaluated using the non-parametric equivalent test (Wilcoxon signed-rank test). There was a statistically significant increase in peak knee flexion moment ($p = 0.031$) after the shift compared to baseline. No statistically significant pre- to post-shift differences for any other dependent variable on either leg was found (all $p > 0.05$). Inter-trial error was calculated for the pre-shift gait trials as a measure of the natural variability in the participants' gait outcome measures. Participants who experienced a change (post minus pre-shift) larger than the inter-trial error can be said to have exhibited a change over their work shift that cannot be explained by natural variability alone. For at least one leg, there were 19 such participants for the kinetic outcomes and sixteen such participants for the kinematic outcomes. The results from this study suggest that a single shift of occupational childcare does have an effect on the childcare educators' knee mechanics during gait.

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1. Motivation

There is a high prevalence of lower limb musculoskeletal injuries in early childcare educators, requiring lost time claims (WSIB Ontario, 2020; Morissette & Qiu, 2023); however, there continues to be little research investigating why these injuries occur. Some studies have evaluated possible ergonomic changes that need to be made (Burford et al., 2017; King et al., 1996; Rasmussen et al., 2020), and what types of exposures childcare educators are subjected to throughout their shift (Grant et al., 1995; Gratz & Claffey, 1996; Labaj et al., 2016; Laudanski et al., 2022), however, no study has assessed whether their workplace environment and daily activities change their knee biomechanics, thereby potentially increasing their risk of lower limb musculoskeletal injuries.

Childcare educators who work with young children perform tasks involving hygiene, care, feeding, games, and crafts. These tasks require positions such as kneeling, squatting, sitting on the floor, and sitting on child-sized furniture, which put their knees into high flexion positions. Previous literature has shown that high knee flexion exposures can result in acute and chronic changes to knee kinematics and kinetics (Gaudreault et al., 2013; Kajaks & Costigan, 2015; Tennant et al., 2018; Weeks et al., 2022), and that high knee flexion movements have been associated with different musculoskeletal disorders (Bahns et al., 2021; Coggon et al., 2000; Cooper et al., 1994). Given that childcare educators engage in high knee flexion movements beyond previously established thresholds associated with higher odds of developing musculoskeletal injuries (Laudanski et al., 2022), it was speculated that childcare educators will have different knee mechanics during everyday activities, such as walking, after their work shift compared to before.

Any differences found in the knee mechanics of childcare educators after their workday compared to before would contribute evidence of an association between altered knee mechanics of childcare educators during walking and their daily activities in the workplace. The results of this study help expand the knowledge in the literature on childcare educators’ risks for developing musculoskeletal injuries and provide insight as to where future research should focus when providing guidelines to reduce the prevalence of musculoskeletal injuries in childcare educators.

2. Literature Review

This literature review will be divided into three sections to familiarize the reader with current risks of childcare educators and the historical ways of assessing musculoskeletal injuries through biomechanical analyses. The first section will introduce the current risk and prevalence of musculoskeletal injuries in childcare educators. This will be followed by evidence linking different types of musculoskeletal injuries and disorders to high knee flexion exposures. The final section will talk about how gait and exposure analyses are commonly performed and biomechanical outcomes that can be used to evaluate risk of musculoskeletal injuries.

2.1 *Childcare Educators*

Childcare is a very important field in that it plays a major role in developing physical, motor, emotional, social, language, and cognitive abilities in children, while also providing support to working families with young children (Bennett, 2020). Childcare educators engage constantly with children through games, crafts, feeding, attending to hygiene needs, and more, all within a setting suitable for the children's safety and enjoyment. Historically, childcare has been classified as a low effort occupation (Whitehead, 1984), however, their daily workplace activities continuously put them in high-risk situations for musculoskeletal injuries (Laudanski et al., 2022).

2.1.1 Workplace Injury Statistics

According to the Workplace Safety and Insurance Board (WSIB) Ontario (2020), 25% of all lost time claims between 2010 and 2019 reported by childcare workers were related to lower extremity injuries. Acute injuries to the knee represented 8% of all approved claims, amounting to a total of $211,609 CAD in benefit costs and 1215.6 lost days (WSIB Ontario, 2020). While these records only include injury claims, Horng et al. (2008) surveyed 85 childcare educators and found 37.2% reported knee pain and Labaj et al. (2016, 2019) questioned 32 childcare workers and found 40% experienced knee pain with severity greater or equal to that of other body segments.

Uppal and Savage (2021) documented that in 2016, 96.3% of all childcare educators in Canada were female and 72.7% of all childcare educators in Canada fell between the age of 25-54 years, with 39.9 years as the median age. Wijnhoven et al. (2006) conducted a survey of people aged 25-64 years which showed that women have a higher prevalence rate of musculoskeletal pain in most anatomic pain sites compared to men. Given the age range and predominant sex of childcare educators, which are non-modifiable factors associated with higher incidences of musculoskeletal injuries and disorders, research exploring causal factors of musculoskeletal injuries that can be altered in childcare work is important.

2.1.2 Occupational Exposures

As mentioned previously, childcare educators spend their day engaging with and caring for young children in an environment suitable for children. Their daily activities require frequent and repetitive lifting, bending, stooping, squatting, reaching, and carrying, all of which have the potential to strain the body causing injury (Grant et al., 1995; Gratz et al., 2002; McGrath, 2007). Grant et al. (1995) found that childcare educators spend approximately 25% of their time kneeling, squatting, or sitting on the floor with the children and spend an additional 25% of their shift seated in chairs designed for small children. Similarly, Laudanski et al. (2022) found through video-based observations of occupational childcare tasks that childcare educators spend the greatest duration of their shift sitting on the floor, sitting on child sized furniture, or in a kneeling position in which both knees are on the ground and their toes are tucked under their buttocks (plantarflexed kneeling). These positions require high knee flexion which has been linked to an increased risk of knee osteoarthritis, increased musculoskeletal injuries, and increased muscle fatigue (Grant et al., 1995; Jung et al., 2010; Reid et al., 2010), with the potential for injury exacerbated if performed using incorrect lifting techniques and awkward body postures, which occur frequently when caring for children as each child has a different stamina level, size, and personality (McGrath, 2007; Yap, 2021).

As little as 30 minutes of cumulative exposure to high knee flexion or greater than 30 instances of transitioning into and out of high knee flexion positions during a shift is believed to increase the risk of lower limb musculoskeletal injuries (Coggon et al., 2000; Cooper et al., 1994; D'Souza et al., 2008; Jensen, 2008). In a recent study, Laudanski et al. (2022) showed that during a typical half-shift (approximately 3.3 hours) childcare educators working with infant, toddler, and preschool-aged children, spent 1.57 hours, 1.55 hours, and 1.24 hours in high flexion positions respectively and that there was an average of 159, 113, and 114 instances of high knee flexion postures in childcare educators caring for infant, toddler, and preschool-aged children respectively. These values fall above the previously mentioned level associated with an increased risk of lower limb musculoskeletal injuries. Other studies focusing on the back found that childcare educators lifted an average cumulative weight of 501 kg over a half-shift (approximately 3.3 hours) with a frequency of one lift every 4 minutes, where 54% of lifts involved children (Labaj et al., 2019; Labaj et al., 2016). The majority of the weight lifted during the half shift observation was during outdoor preparation and changing diapers (Labaj et al., 2019). The average weight lifted during these two tasks was 7.7 kg and 12.2 kg with an average lifting frequency of 1 lift every 1.67 minutes and 1 lift every 1.28 minutes, respectively (Labaj et al., 2019). Although these levels of exposure do not exceed the recommended limits for lifting, these limits do not account for the muscle stability that is required for lifting a child that moves in unpredictable ways (Labaj et al., 2019).

Developing interventions to reduce the prevalence of musculoskeletal injuries and pain-related absences in childcare educators is difficult due to the lack of research in this field. Efforts have been made to develop successful interventions by means of evaluating childcare educators in two countries; one with high rates of musculoskeletal injuries (Japan) and another with low rates (Sweden) (Shimaoka et al., 1997). Though differences between the two countries were evident, including a difference in their rating of perceived exertion and local physical workload, the differences seen were not sufficient to explain the differences in the magnitude of musculoskeletal problems (Shimaoka et al., 1997). To my knowledge, only two recent studies (Burford et al., 2017; Rasmussen et al., 2020) have reviewed the effectiveness of suggested interventions to reduce the number of musculoskeletal injuries. A study conducted in Germany by Burford et al. (2017) examined if a combination of situation-orientated and behaviour-orientated measures affect the working postures and duration of awkward working postures in preschool teachers. The intervention included participatory ergonomics with new furniture (e.g., seating options, table options, lighter children's beds, diaper changing tables with a step) and a 90-minute individualised awareness session (Burford et al., 2017). They found significant alterations in the adoption of seated and knee-straining postures, and the percentage of time the knee joint was in a neutral-risk position increased, though the increase was not significant. Another study by Rasmussen et al. (2020) conducted in Denmark examined the effectiveness of a 20-week training workshop led by physiotherapists and occupational therapists, which taught childcare educators how to identify and analyze musculoskeletal risk factors and how to create effective solutions. This training program did not show any effects on physical exertion and musculoskeletal pain; however, it was deemed to be feasible and effective in reducing musculoskeletal pain related absences (Rasmussen et al., 2020). Despite efforts in reducing the number of musculoskeletal injures in childcare educators, more research into the ergonomic exposures of childcare educators and their associated micro-injuries is required for the development of more effective interventions.

2.2 *Lower Limb Musculoskeletal Injuries*

Lower limb musculoskeletal injuries commonly involve muscles, tendons, ligaments, nerves, and other tissues, and usually present as inflammation, pain, discomfort, or tingling (Okunribido & Lewis, 2010). Some of the most reported lower limb overuse injuries and disorders are knee osteoarthritis, meniscal lesions, hamstring injuries, and patellofemoral injuries (Bulat et al., 2019; Okunribido & Lewis, 2010). This section will review the risk of lower limb musculoskeletal injuries following high knee flexion exposures as well as different lower limb musculoskeletal injuries and their presentation in lab-based gait analyses. Summaries of the changes in gait kinematics and kinetics in each of the conditions below can be found in Table 2.1 and in Figure 2.1 at the end of section 2.2.

2.2.1 Risk of Musculoskeletal Injuries Following Kneeling Exposure

There have been no longitudinal studies carried out to assess the risk of musculoskeletal injuries associated with kneeling exposure. However, studies that compare lower limb mechanics before and after acute kneeling exposure, and studies that examine the lower limb mechanics of people with long-term exposure to kneeling can provide insight into risk. This insight is obtained by determining if any observed 'abnormal' mechanics (those that differ from pre-kneeling exposure or those that differ from controls) match those that have been linked to a risk of injury or have been observed in pathological populations.

There are a few studies that have shown that knee kinetics and kinematics can be altered following knee straining postures (Gaudreault et al., 2013; Kajaks & Costigan, 2015; Tennant et al., 2018). Kajaks and Costigan (2015) had ten healthy males complete ten walking trials, followed by three ten-minute cycles of static kneeling (with their buttocks in contact with their heels as much as possible), followed by another ten walking trials. In this study, a root mean squared difference between the waveform of each trial and the mean waveform across trials was calculated within each condition (pre- and post-kneeling) and interpreted as a measure of variation across trials. They found no significant difference between the root mean squared difference (RMSD) in the pre-kneeling walking trial compared to the post-kneeling walking trial for knee adduction angle, knee flexion moment, and knee adduction moment but found a significant increase in the RMSD of knee flexion angle during post kneeling gait indicating an increase in knee flexion angle variation in post-kneeling walking (Kajaks & Costigan, 2015). The authors additionally calculated an RMSD between the post-kneeling gait waveforms and the mean pre-kneeling waveform, interpreted as a measure of the difference in amplitude between the pre- and post-kneeling conditions (Kajaks & Costigan, 2015). They found that the RMSD significantly exceeded their measure of variability from the pre-kneeling trials, indicating a meaningful increase for knee flexion angle, knee adduction angle, knee flexion moment and knee adduction moment (Kajaks & Costigan, 2015). Their results indicate that there are acutely altered loading patterns during gait as a result of sustained static kneeling (Kajaks & Costigan, 2015). A different study (Tennant et al., 2018) with similar motives looked at knee adduction moment, peak vertical rate of loading, and quadriceps activation onset in 40 healthy individuals during gait and squatting transitions before, right after, and 30-minutes after a kneeling protocol that was intended to represent a workplace activity rather than static exposure. Tennant et al. (2018) found the peak knee adduction moment during gait was significantly greater immediately following the kneeling exposure but was not significantly different from baseline 30 minutes post-kneeling. The authors also found no significant difference in peak vertical rate of loading but did see a delay in quadriceps activation both immediately after kneeling and 30 minutes after kneeling (Tennant et al., 2018). In addition, the authors found an increase in frontal plane knee motion during squatting transitions, both immediately after and 30 minutes after the occupational kneeling protocol, which may be associated with elevated risks of knee injuries (Tennant et al., 2018). The biomechanical changes seen in Tennant et al. (2018) past 30 minutes post-kneeling, fall in line with the results of the study by Gaudreault et al. (2013) in which, instead of evaluating biomechanical parameters after an in-laboratory kneeling protocol, they evaluated differences seen in individuals with knee straining occupations compared to individuals in non-knee straining occupations during gait. Participants in the knee-straining occupation group had to be exposed to daily sustained deep knee flexion postures during working hours for at least 30 minutes per day for at least the past five years. Gaudreault et al. (2013) found that the group in knee straining occupations (KS) had greater mean knee flexion angle at foot contact and smaller angle range than individuals in non-knee straining occupations (non-KS). They also found that non-KS had greater mean peak knee flexion during swing phase (Gaudreault et al., 2013). For adduction/abduction movements KS had greater knee adduction at initial foot contact and their knees were not abducted during the first portion of swing phase as compared to non-KS (Gaudreault et al., 2013). Lastly internal/external angle range of the knee was greater for KS (Gaudreault et al., 2013). The differences in the knee kinematics between the KS and the non-KS groups in Gaudreault et al. (2013), and the continued differences seen 30 minutes after an occupational kneeling protocol in Tennant et al. (2018) indicate that there may be cumulative and persistent effects of knee straining postures that might explain the increased incidence of musculoskeletal injuries in childcare educators.

2.2.2 Osteoarthritis

Osteoarthritis is a complex disease with both local and systemic characteristics. One way in which osteoarthritis presents is as a loss of, and/or damage to, articular cartilage. The damage to articular cartilage can be caused by joint straining activities required in the workplace. For example, jobs that require prolonged knee flexion or frequent transitions into and out of squatting or kneeling have been associated with an increased risk of knee osteoarthritis (Coggon et al., 2000; Cooper et al., 1994). Horng et al. (2015) demonstrated that cartilage can deform following 10 minutes of different high knee flexion positions including kneeling, heel sitting, and squatting. The average local deformation to the cartilage of the knee was -6.3 ± 2.2%, -6.1 ± 1.7%, and -7.0 ± 2.6% after kneeling, heel sitting, and squatting, respectively (Horng et al., 2015). In addition to high knee flexion positions causing deformation to cartilage, static compression has also been shown to reduce chondrocyte activity, whose main role is to synthesize and maintain the extracellular matrix of articular cartilage (Chen & Sah, 1998). Though osteoarthritis can occur in multiple joints in the body, this section will focus on osteoarthritis of the knee and how it presents during gait.

The most common activity that is reported as difficult by those with knee osteoarthritis is walking (Guccione et al., 1994). Joint degradation can cause abnormal loading and stresses on the joints which likely contributes to the difficulty of walking (Baliunas et al., 2002). Compared to healthy controls, individuals with knee osteoarthritis walk at a reduced speed, have a longer double support phase, and a smaller stride length (Astephen & Deluzio, 2005; Baliunas et al., 2002; Brinkmann & Perry, 1985; Chen et al., 2003; Smith et al., 2004). They also tend to exhibit greater knee flexion at heel strike, less knee flexion during stance phase, less knee extension excursion during midstance, and an increased average adduction excursion (Astephen & Deluzio, 2005; Childs et al., 2004; Heiden et al., 2009; Mündermann et al., 2005; Rudolph et al., 2007; Zeni & Higginson, 2009). Individuals with knee osteoarthritis also have altered gait kinetics that include reduced heel strike forces on the affected limb, a decreased peak external knee extension moment during terminal stance, and an increased peak adduction moment when compared to healthy controls (Astephen & Deluzio, 2005; Baliunas et al., 2002; Heiden et al., 2009; Na et al., 2018; Simic et al., 2011). With osteoarthritis, individuals will also have an increase in peak knee flexion moment at foot contact (Na et al., 2018) but a lower knee flexion moment during stance phase (Kaufman et al., 2001; Rudolph et al., 2007; Zeni & Higginson, 2009). Regarding muscle activation, Heiden et al. (2009) found that there is an increased lateral muscle activation during stance phase which correlated with the magnitude of the adduction moment. The authors suggest that this may be a way of aiding in the stabilization of the external knee adduction moment (Heiden et al., 2009).

Pain is the most common complaint in individuals with knee osteoarthritis (Hunter et al., 2008). Several of the kinematic and kinetic variables mentioned in this section are associated with the pain experienced by individuals with knee osteoarthritis (Marriott et al., 2019; Robbins et al., 2011; Yamagata et al., 2021). For example, greater peak knee adduction moments, adduction impulse and internal rotation moments during gait were associated with an increased chance of pain after walking, while greater knee flexion, extension, and external rotation moments during gait were associated with a decreased chance of experiencing pain after walking

(Marriott et al., 2019). Likewise, Robbins et al. (2011) found that increased BMI, decreased knee extensor strength, increased knee adduction moment impulse, and higher steps per day were all associated with an increase in pain experienced in individuals with knee osteoarthritis. When investigating differences between severe symptomatic knee osteoarthritis patients and mild symptomatic knee osteoarthritis patients, there were no differences in femorotibial angle and gait speed, but there was a significantly higher knee adduction moment and medial knee contact force during mid-stance to terminal stance (Robbins et al., 2011). Another variable to consider when looking at the degree at which changes in biomechanical variables in individuals with knee osteoarthritis is seen, is self-reported knee instability. Farrokhi et al. (2015) found that self-reported knee instability in individuals with knee osteoarthritis was associated with a greater chance of experiencing moderate or extreme pain when walking and a greater chance of reporting difficulty while walking on flat surfaces. Individuals with self-reported knee instability had greater knee motion excursion during early stance phase but not the initial knee extension phase of gait (Farrokhi et al., 2015). Individuals with knee osteoarthritis and unstable knees also walked with significantly lower total support moment and reduced contributions from the hip extensors and plantar flexors during early stance phase compared to individuals with knee osteoarthritis that report no knee instability (Farrokhi et al., 2015).

2.2.3 Meniscal Lesions

The meniscus in the knees distribute force and helps spread joint fluid evenly to lubricate and nourish the knee (Harvard Health Publishing, 2019). Meniscal tears can be a degenerative injury associated with repetitive exposures to knee-straining positions and have been proposed as an initiatory event for knee osteoarthritis (Bahns et al., 2021; Englund, 2004; Roemer et al., 2015). Meniscus tears and degeneration have been associated with joint space narrowing, which is also a radiographic sign of knee osteoarthritis (Madan-Sharma et al., 2008). However, unlike osteoarthritis, there are differences in the literature as to whether meniscal degeneration and lesions result in changes in gait biomechanics. A study by Russell et al. (2017) found that subjects with posterior meniscal horn lesions had a lower Knee injury and Osteoarthritis Outcome Score (KOOS) compared to matched controls without meniscal lesions and displayed significant changes in cartilage compositions with increasing changes at one year and two year follow ups. However, at baseline, one year, and two years, there were no differences in peak knee flexion and adduction angles, peak knee flexion and adduction moments, or peak knee flexion and adduction moment impulses during stance phase of gait between the two groups (Russell et al., 2017).

2.2.4 Overexertion Injuries

Sprains and strains can be caused by a sudden trauma or through overuse where activities are repeated in a frequency where the muscles, tendons, and ligaments do not have enough time to heal. Exercise induced muscle damage can present as muscle soreness, stiffness, reductions in force, and elevated intramuscular proteins in the blood (Byrne et al., 2004; Tsatalas et al., 2013). Tsatalas et al. (2013) found that 48 hours post eccentric hamstring exercise, participants displayed decreased step length, increased stride frequency, and wider base of support. The authors also found increased knee flexion at foot-strike and mid-stance, a more extended knee joint during swing phase, and a reduced overall knee ROM during the entire gait cycle (Tsatalas et al., 2013). Also noted was that the maximum knee flexion moment during stance phase was increased and that the maximum knee extension moment during pre-swing phase decreased (Tsatalas et al., 2013). A similar study examining gait during muscle pain, induced muscle pain through hypertonic saline injections and like Tsatalas et al. (2013) found lower extensor moments compared to when the participants had no pain (Henriksen et al., 2007). Henriksen et al. (2007) had different results when it comes to finding differences in knee joint angles and peak knee flexion moments in that there were no changes in either variable. New variables that were examined demonstrated that pain in the vastus medialis reduced electromyography activity in both the vastus medialis and vastus lateralis during the loading response phase of gait but that there were no changes in EMG activity during the concentric quadriceps contraction during midstance (Henriksen et al., 2007). There has also been found to be a reduction in maximal voluntary isometric knee extension torque (Graven-Nielsen et al., 2002). Though exercise induced muscle damage is often temporary, over working the lower extremity during this time can lead to more detrimental injuries.

It is important to note that certain factors change the extent to which a sprain or strain occurs. The first factor to consider is age. Noyes and Grood (1976) demonstrated that ligaments in younger individuals have a two to three times larger elastic modulus, ultimate tensile stress, and strain energy to failure than those individuals greater than 60 years of age and that younger individuals are much more resistant to ligamentous stretching. The authors also found a difference in mode of failure where younger individuals are more prone to ligamentous detachment and rupture injuries whereas older individuals have a higher incidence of bone avulsion (Noyes & Grood, 1976). Another factor that has been shown to affect the extent of injury is sex. Studies examining eccentric knee flexor strength following a hamstring injury in female athletes did not report any significant difference (Bourne et al., 2019; Collings et al., 2021) while those studies that include predominantly male athletes found significant deficits in eccentric knee flexor strength (Lee et al., 2009; Maniar et al., 2016). Also, by participating in sports that induce lower limb muscle fatigue, there is an increased risk of a hamstring injury

(Huygaerts et al., 2020). Pinniger et al. (2000) found that after performing hamstring fatiguing exercises, there was an earlier reduction in rectus femoris activity and earlier onset of semitendinosus and biceps femoris activity during the sprint cycle. Pinniger et al. (2000) also found changes in lower limb kinematics including decreased hip flexion and increased knee extension in swing phase, decreased shank angular velocity before heel strike and decreased angular displacement of the trunk, thigh, and shank segments during late swing phase of the sprint cycle. It is speculated that increased knee stabilizing demands during fatigue could place greater loads on the hamstring, increasing the likelihood of a strain injury (Huygaerts et al., 2020). Exposure to high knee flexion positions have also been shown to induce muscle fatigue (Jung et al., 2010). The high duration and frequency that childcare educators engage in these high knee flexion positions (Laudanski et al., 2022) suggests that we may see similar changes the educators' knee biomechanical variables.

2.2.5 Patellofemoral Pain Syndrome

Patellofemoral pain is a term used to describe pain behind or around the patella and is aggravated when the knee is flexed and weightbearing (Collins et al., 2018). Though this injury is most common in athletes, patellofemoral pain syndrome can occur non-athletes as well and can cause pain and stiffness making it difficult to perform daily activities. Glaviano et al. (2022) conducted a systematic review with a meta-analysis indicating that there is strong evidence for individuals with patellofemoral pain having greater pain during walking, running, squatting, and moderate evidence for an increase in pain during jumping/landing, knee extension, and patellofemoral loading tasks and step tasks. Biomechanical factors that have been found to be associated with patellofemoral pain are increases in knee valgus angle and moment during walking and an increase in peak knee flexion angle specific to male recreational runners (Salsich

& Long-Rossi, 2010; Yang et al., 2022). This pain during common activities of daily living has the potential to reduce quality of life and changes to their lower limb biomechanics that can lead to further progression in musculoskeletal injuries and will be discussed further in the following paragraphs.

Research has shown that individuals with patellofemoral pain with different levels of quadriceps activation have significantly different walking mechanics compared to healthy controls. Compared to healthy controls, individuals with patellofemoral pain syndrome have been shown to have a significantly higher peak loading rate, peak axial shank acceleration, and peak thigh acceleration during gait and a significantly higher vertical (downward) ankle velocity prior to heel strike and angular velocity at the instant of heel strike (Radin et al., 1991). Individuals with patellofemoral pain syndrome also displayed less knee flexion during heel strike and throughout stance phase compared to healthy controls (Radin et al., 1991). Another interesting finding is that healthy controls and those with patellofemoral pain exhibit similar patterns in knee flexor activity and similar periods of simultaneous quadricep activity immediately before heel strike but that the quadricep activity remains active longer in the healthy control group compared to the group with knee pain (Radin et al., 1991). Seeley et al. (2017) demonstrated that studies investigating lower limb biomechanics in individuals with patellofemoral pain should also consider breaking the groups of individuals with knee pain into two groups based on the neuromuscular activation level of their quadriceps as the amount of neuromuscular activation may confound the motor function seen in individuals with patellofemoral pain. Seeley et al. (2017) took a group of individuals with patellofemoral pain and similar self-reported pain levels and split them into either the quadricep deficient (QD) group or the non-quadricep deficient (NQD) group and found that the QD group had four degrees less knee flexion during stance phase than the individuals in the NQD group, which is similar to the findings of Radin et al. (1991) showing that individuals with patellofemoral pain had less knee flexion than healthy controls. The NQD group also exhibited 5% greater vertical ground reaction force at and around peak impact and 5% less vertical ground reaction force during the unloading portion of stance phase of gait than the QD group (Seeley et al., 2017), which is something that was not seen when just assessing a generalized group of individuals with patellofemoral pain who did not appear to have any abnormality in shape or amplitude of the vertical ground reaction force (Radin et al., 1991). Seeley et al. (2017) further discovered that net knee extension torque, net plantar flexion torque, and net hip extension torque was greater in the NQD group relative to the QD group during the early portion of stance phase, as well as net knee adduction torque and net hip abduction torque was greater for the QD group. Therefore, there is a difference in gait mechanics between healthy controls and individuals with PFP which appears to be further affected if the individuals also display evidence of decrease quadricep neuromuscular activation.

Again, because much of the literature on patellofemoral pain is in relation to athletes and strenuous movements including running and jumping, it is unclear if we will see similar biomechanical changes in non-athletes performing walking or occupational tasks. The term "occupational athlete" or "industrial athlete" is beginning to be recognized in the literature for occupational workers in strenuous jobs who, like athletes, use their physical abilities to perform a task, sometimes lifting, bending, or pushing in patterns identical to a sports athlete, for the entire duration of their workday (DiVincenzo, 2022). Like sports athletes, occupational athletes can be vulnerable to injuries like patellofemoral pain, which this section has described can result in changes to lower limb mechanics and should be studied in workers.

2.2.6 Changes Preceding Musculoskeletal Disorder Initiation

Outcome variables such as knee flexion and adduction moment during gait have commonly been used in the literature as a surrogate measure to assess musculoskeletal disorder risk as these variables have been found to predict the disorder progression (Miyazaki et al., 2002; Teng et al., 2015). However, whether changes in these variables can be used to predict the initiation is less clear. Studying which variables, if any, during gait change prior to musculoskeletal injury initiation is challenging because typically no one is being studied until they already have the disorder, and there is no guarantee they will develop the disorder even with high risk factors. To my knowledge, there are no studies that assess gait changes that precede musculoskeletal ailment initiation. However, there have been studies using mice that have found an increase in pro-inflammatory cytokines and matrix degrading enzymes in both the synovium and articular cartilage (Liao et al., 2020) and decreases in the pericellular matrix micromechanics (Chery et al., 2020) within a week of an injury and preceded the events of post-traumatic osteoarthritis development. These findings indicate that there may be changes in the knee that occur prior to musculoskeletal ailment development in humans, but it is unclear if any of these changes can be seen through kinetic and kinematic gait alterations. Therefore, at the current time, using surrogate measures continues to be the most appropriate approach to assessing musculoskeletal injury risk.

Knee osteoarthritis development has also been associated with occupational activities requiring high knee flexion (Coggon et al. 2000; Cooper at al., 1994). As mentioned in section 2.2.1, these high knee flexion positions have been shown to result in changes to knee kinematics and kinetics during gait (Kajaks & Costigan, 2015; Tennant et al., 2018; Weeks et al., 2022). These changes with high knee flexion exposure reflect the changes and direction of change of those seen with different musculoskeletal ailments of the knee, as summarized in 2.2.2 to 2.2.5. The similarities of change between high knee flexion exposure and musculoskeletal conditions lead one to speculate that cumulative changes in knee kinetics and kinematics occur with repetitive exposure and may potentially lead to the development of musculoskeletal ailments, however there are no studies that the report the order in which changes of the knee occur preceding initiation of the disorder. A summary of the lower limb biomechanical changes during gait and their associated cause (i.e., high knee flexion exposure or musculoskeletal injury) can be found in Table 2.1. A Venn diagram comparing the biomechanical differences seen in musculoskeletal ailments and high knee flexion exposure can be found in Figure 2.1.

Table 2.1: Summary of the knee biomechanical changes during gait and their associated conditions.

Group/Condition		Altered knee mechanics during gait*					
		Flexion Angle	Flexion Moment	Adduction Angle	Adduction Moment	Extension Angle	Extension Moment
High Knee Flexion Exposure	Post-kneeling exposure	Weeks et al., 2022^{FC}; Kajaks & Costigan, 2015^{G} (RMSD)	Kajaks & Costigan, 2015^{G} (RMSD); Weeks et al., 2022^{G}	Kajaks & Costigan, 2015^{G} (RMSD);	Kajaks & Costigan, 2015^{G} (RMSD); Tennant et al., 2018^{G}; Weeks et al., 2022^{G}		
	30 minutes post kneeling exposure				Tennant et al., 2018^{G}		
	Knee straining workers	Gaudreault et al., 2013^{FC}; Gaudreault et al., 2013^{S}		Gaudreault et al., 2013^{FC}; Gaudreault et al., 2013^{G}			
Osteoarthritis	Osteoarthritis	Heiden et al., 2009^{FC,ES}; Baliunas et al., 2002^{MS}; Rudolph, Schmitt, & Lewek, 2007^{FC}	Kaufman et al., 2001^{G}; Rudolph, Schmitt, & Lewek, 2007ES; Zeni & Higginson, 2009^{S}; Heiden et al., 2009^{ES,TS}; Baliunas et al., 2002^{G}	Rudolph, Schmitt, & Lewek, 2007^{FC,ES}	Baliunas et al., 2002^{G}; Na et al., 2018^{G}; Rudolph, Schmitt, & Lewek, 2007^{S}; Heiden et al., 2009ES	Heiden et al., 2009^{TS}	Heiden et al., 2009^{TS}; Na et al., 2018^{G}; Baliunas et al., 2002^{G}
	Painful knee OA compared to asymptomatic knee OA		Marriott et al., 2019^{G}		Robbins et al., 2011^{TS}; Marriott et al., 2019^{G}		Marriott et al., 2019^{G}
Meniscal Lesions	Meniscal lesions	Russell et al, 2017^{G}	Russell et al, 2017^{G}	Russell et al, 2017^{G}	Russell et al, 2017^{G}		

Strains and Sprains	Post-eccentric hamstring exercise	Tsatalas et al., 2013^{FC}; Tsatalas et al., 2013^{S}	Tsatalas et al., 2013^{S}				Tsatalas et al., 2013^{TS}
	Induced muscle pain	Henriksen et al., 2007^{G}	Henriksen et al., 2007^{G}			Henriksen et al., 2007^{G}	Henriksen et al., 2007^{G}
Patellofemoral Pain	Patellofemoral pain	Radin et al., 1991^{FC}; Radin et al., 1991^{S}		Salsich & Long-Rossi, 2010^{G}; Yang et al., 2022^{G}	Salsich & Long-Rossi, 2010^{G}; Yang et al., 2022^{G}		
	Patellofemoral pain in male recreational runners				Yang et al., 2022^{G}		
	Quadricep deficient with PFP compared to PFP	Seeley et al., 2017^{S}					

		Flexion Moment Impulse	Adduction Moment Impulse	Peak Vertical Rate of Loading	Positive Peak Knee Power	Flexion Torque	Extension Torque
High Knee Flexion Exposure	Post-kneeling exposure		Weeks et al., 2022^{G}	Tennant et al., 2018^{G}	Weeks et al., 2022^{G}		
	30 minutes post kneeling exposure			Tennant et al., 2018^{G}			
Osteoarthritis	Painful knee OA compared to asymptomatic knee OA		Marriott et al., 2019^{G}; Robbins et al., 2011^{G}				
Meniscal Lesio	Meniscal lesions	Russell et al., 2017^{S}					
Strains and Sprains	Hamstring injury >5 months prior					Silder et al., 2010^{G}	

	Male athletes up to 19 ± 12.5 months after a moderate to severe hamstring injury					Lee et al., 2009^{G}	
Patellofemoral Pain	Patellofemoral pain			Radin et al., 1991^{G}			
	Quadricep deficient with PFP compared to PFP						Seeley et al., 2017^{ES}

*Compared to controls, pre-exposure, or non-knee straining workers

Note: The variable defined at foot contact is instantaneous. All other variables are the peak value of that phase unless otherwise specified in brackets.

FC = Foot contact; ES = Early stance; MS = Midstance; TS = Terminal stance; S = Stance phase; G = Full Gait

Blue = Increase; Green = Decrease; Grey = No change

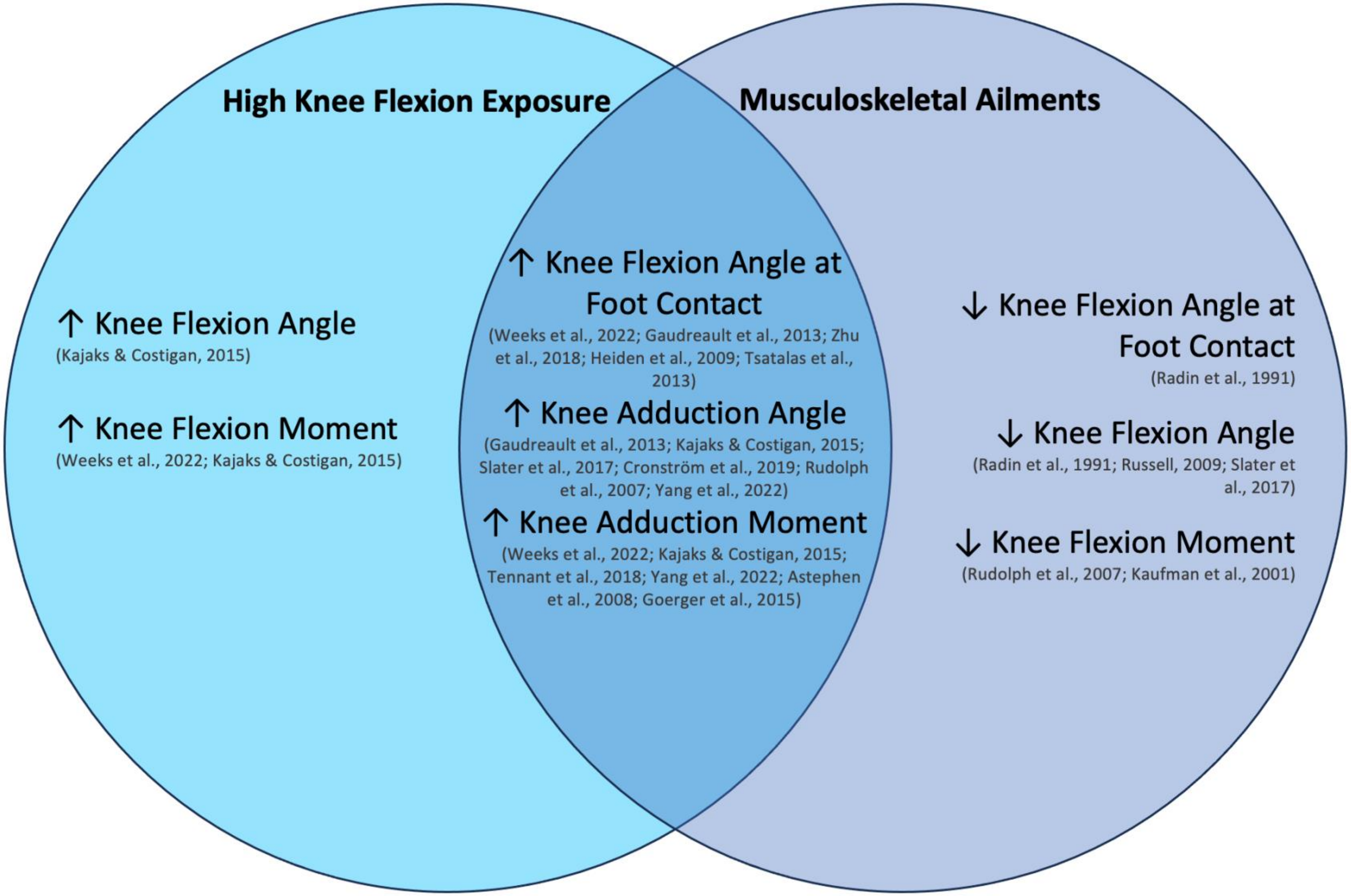

Figure 2.1: Venn diagram displaying the biomechanical changes of the knee seen with high knee flexion exposure compared to musculoskeletal ailments (i.e., osteoarthritis, meniscal lesions, sprains and strains, and patellofemoral pain syndrome).

2.3 *Gait Analysis*

Changes in gait are observed frequently in the literature in individuals with musculoskeletal injuries or disorders. Variables including, but not limited to, knee adduction, flexion, and extension angles and moments, appear to differ between individuals with musculoskeletal injuries in comparison to healthy, asymptomatic controls. The changes in these variables are also sometimes dependent on the phase of the gait cycle. This section will elaborate on how gait is commonly assessed in the laboratory, including how each phase of the gait cycle is typically defined, and which variables are normally measured when analysing changes in gait following a musculoskeletal injury.

2.3.1 Procedure

To analyse lower limb kinetics and kinematics during gait in individuals with musculoskeletal injuries and asymptomatic controls, researchers will use a combination of motion capture systems and force plates. For the motion capture system, researchers will typically collect the kinematic data at a sampling rate between 60 Hz and 250 Hz (Gaudreault et al., 2013; Heiden et al., 2009; Marriott et al., 2019; Na et al., 2018; Russell et al., 2017; Tennant et al., 2018; Tsatalas et al., 2013). While active and passive motion capture systems using clusters of infrared-emitting diodes and reflective markers respectively are used frequently in the literature, the use of markerless motion capture systems is becoming more common. With markerless motion capture systems, software (e.g., Theia3D, OpenCap) will identify and track people in the video images and then compute the three-dimensional position and orientation of each segment of the tracked person (Theia Markerless, Inc., n.d.). The use of markerless motion capture helps avoid the time-consuming process of placing all the markers on the body (Theia Markerless, Inc., n.d.).

As the current gold standard for motion capture is marker-based optical motion capture (Filho, 2005; Kidziński et al., 2020), there have been many studies that have reviewed how markerless motion capture compares to marker-based systems (Ceseracciu et al., 2014; Ito et al., 2022; Kanko et al., 2021a; Song et al., 2023). Kanko et al. (2021a) demonstrated that when comparing the markerless and marker-based motion capture during gait, the average root mean square difference (RMSD) for the knee and ankle joint centers were less than 2.5 cm and the hip was 3.6 cm. The authors also found that lower limb segment angles (excluding rotations about the long axis of the segment) relative to the global coordinate system were very similar between systems with a RMSD less than 5.5° (Kanko et al., 2021a). Similarly, Song et al. (2023) compared markerless and marker-based motion capture during eight movement tasks and found that the ankle and knee joint angle estimates from the markerless motion capture system closely matched the marker-based system with RMSD ≤ 5.9° and RMSD for the joint moments ≤ 2.66% height x weight. The hip angles and moments had larger differences between the two systems with a RMSD of 6.7°-15.9° and up to 7.15% height x weight (Song et al., 2023). Both studies concluded that markerless motion capture is an appropriate alternative to marker-based optical motion capture when the benefits of a markerless system are preferred, such as with in-field studies.

In addition to motion capture, researchers also collect data using force plates. Data from the force plates are typically sampled between 1000 Hz and 2100 Hz (Farrokhi et al., 2015; Heiden et al., 2009; Henriksen et al., 2007; Kajaks & Costigan, 2015; Marriott et al., 2019; Na et al., 2018; Russell et al., 2017; Tennant et al., 2018; Tsatalas et al., 2013). The data from the force plates is typically synchronized with the motion capture data to help define the different phases of gait and calculate the joint moments (Farrokhi et al., 2011; Gaudreault et al., 2013; Henriksen et al., 2007; Kajaks & Costigan, 2015; Na et al., 2018; Tennant et al., 2018; Tsatalas et al., 2013). Both the motion capture data and the force plate data are often filtered to remove noise.

Two of the studies that were frequently mentioned in section 2.3 (Henriksen et al., 2007; Tennant et al., 2018) controlled the gait speed of the participants, while most of the remaining studies report that they allowed participants to walk at their preferred normal walking speed (Edd et al., 2017; Farrokhi et al., 2015; Gaudreault et al., 2013; Heiden et al., 2009; Marriott et al., 2019; Tsatalas et al., 2013). Heiden et al. (2009) justified the self-selected gait velocity method by explaining it helps reflect the kinetics and kinematics that the participants with the musculoskeletal injuries experience daily. However, a study by Zeni and Higginson (2009) found that differences in gait mechanics between those with knee osteoarthritis and healthy controls decrease significantly when the same individuals are instructed to walk at a controlled speed of 1.0m/s. Therefore, reflecting on whether it is more important to understand an individual's daily knee mechanics or to evaluate a true difference between groups should be done when deciding on a whether to use a controlled gait velocity.

2.3.2 Variables Assessed

During gait analyses comparing those with musculoskeletal injuries to healthy controls, there are many variables assessed during different phases of gait. This section will start by defining how most researchers define the different phases of gait and sub-phases during the stance phase, followed by definitions of the kinematic and kinetic variables assessed during the different phases of gait.

Though different terminology is sometimes used to describe the key transition points of gait, it is generally accepted that there are two major phases of gait: stance phase and swing phase (Pirker & Katzenschlager, 2017). Approximately 60% of the gait cycle is spent in stance phase which is typically divided into initial contact (sometimes referred to as heel strike or foot-contact), loading response (weight acceptance), mid-stance, terminal stance, and pre-swing (Pirker & Katzenschlager, 2017). The swing phase is the remaining 40% of the gait cycle and is divided into initial swing (toe-off or foot off), mid-swing (tibia vertical), and terminal swing (Pirker & Katzenschlager, 2017). To define these different stages of gait, many of the studies mentioned previously used a combination of the motion capture data and the force plate data. Some studies use a force plate threshold method to define foot-contact and toe off, such as 5% of the peak vertical ground reaction force over 8 frames (Kajaks & Costigan, 2015), 2% of the participants body weight identified through vertical ground reaction forces (Gaudreault et al., 2013), or a vertical ground reaction force of 20N (Tennant et al., 2018) or 10 N (Tsatalas et al., 2013). Other studies included the motion capture data to help define the different sub-phases within the stance phase. For example, Na et al. (2018) defined the weight acceptance phase of stance starting with heel strike as defined by 50N on the force plate and ended at first peak of the knee flexion angle. Na et al. (2018) then defined mid-stance starting at the first peak knee flexion angle and stopping at the first peak knee extension angle. Analysis of knee kinetics and kinematics during swing phase appear to be of less interest when researching musculoskeletal injuries, but those who do analyse it, look at swing phase as a whole rather than dividing it into different sub-phases (Gaudreault et al., 2013).

The kinematic variables that are commonly assessed during the gait cycle of those with musculoskeletal injuries and asymptomatic controls are knee angles such as flexion/extension, adduction/abduction, and internal/external rotation angles at foot contact, or the minimum or maximum during stance phase and swing phase (Edd et al., 2017; Gaudreault et al., 2013;

Heiden et al., 2009; Kajaks & Costigan, 2015; Marriott et al., 2019; Russell et al., 2017; Tsatalas et al., 2013), hip angles such as maximum hip flexion and extension angles during stance and hip range of motion over the entire gait cycle, and ankle angles such as maximum dorsiflexion angle during stance, maximum plantar flexion over the entire gait cycle, and ankle range of motion over the entire gait cycle (Tsatalas et al., 2013). When presenting these variables, the angles are typically averaged over the accepted trials and normalized to either 100% of stance or 100% of gait cycle (Marriott et al., 2019; Tsatalas et al., 2013).

The kinetic variables of gait that are commonly assessed in relation to musculoskeletal conditions are knee flexion, extension and adduction moments, and knee flexion and adduction moment impulses (Edd et al., 2017; Farrokhi et al., 2015; Heiden et al., 2009; Kajaks & Costigan, 2015; Marriott et al., 2019; Na et al., 2018; Russell et al., 2017; Tennant et al., 2018; Tsatalas et al., 2013). Some studies evaluate these kinetic variables at specific times or during specific intervals during stance phase. For example, Heiden et al. (2009) evaluated peak knee adduction and flexion moment during early stance, and peak knee flexion and extension moment during late stance and Na et al. (2018) evaluated peak knee flexion and adduction moment during early stance and peak knee extension and adduction moment during mid to late stance. In addition to knee kinetic variables, Tsatalas et al. (2013) also evaluated flexion and extension moments of the hip and ankle dorsiflexion and plantarflexion moments during stance phase. Moments are typically normalized to body weight and height (BWxH) in order to remove potential confounding factors related to physical characteristics between individuals (Moisio et al., 2003).

Some studies report internal moments while others report external moments. External moments can be calculated through inverse dynamics using the motion capture and force plate data. Internal moments are equal and opposite to the external flexion moments calculated through inverse dynamics (Farrokhi et al., 2015). Many of the studies mentioned previously report the external moments, though some do not explicitly say. These moments are defining two different types of forces that are acting on the joint; external being forces from an external source such as the ground, while internal moments are caused from the muscles and passive structures such as the ligaments, within the joints.

3. Objective and Hypotheses

Objective: To evaluate whether there are differences in knee flexion angle at foot contact, peak knee adduction angle during stance, peak external knee flexion moment during stance, and peak external knee adduction moment during stance before and after a childcare educator's work shift.

As mentioned in the literature review, there are many different outcome variables that are assessed during gait when investigating high knee flexion exposure repercussions and musculoskeletal ailments. The outcome measures above were chosen for the following reasons: To my knowledge, there are no studies that evaluate knee biomechanics during gait before and after a workday in occupations that require high knee flexion activities. Therefore, the outcome variables chosen for this thesis were those that were assessed in studies that looked at the acute effects of 30 minutes of high knee flexion (Kajaks & Costigan, 2015; Tennant et al., 2018; Weeks et al., 2022) and the study by Gaudreault et al. (2013) that looked at the long-term effects of workers in a knee-straining occupation. While none of the studies' objectives aligned directly with this thesis' objective, selecting variables from a mixture of studies looking at acute bouts of high knee flexion and being in a knee-straining occupation long term, felt appropriate for a study evaluating the effect of a workday that may have many bouts of high knee flexion. The variables chosen from these studies all displayed significant differences after their protocol, or when compared to individuals in non-knee straining occupations and are also variables that are extensively studied in association with different musculoskeletal injuries and disorders (Baliunas et al., 2002; Edd et al., 2017; Henriksen et al., 2007; Rudolph et al., 2007; Russell et al., 2017; Tsatalas et al., 2013; Yang et al., 2022).

Hypothesis: Childcare educators' will have an increased flexion angle at foot contact, an increased peak knee adduction angle during stance, an increased peak external knee flexion moment during stance, and an increased external peak knee adduction moment during stance at the end of their shift compared to their baseline gait trials at the beginning of the day.

The directionality of this hypothesis is based on the direction in which outcome variables changed after acute high flexion exposure in previous studies (Kajaks & Costigan, 2015; Tennant et al., 2018; Weeks et al., 2022).

4. Methods

4.1 Study Population

For this study, 21 childcare educators (working with children aged 0 to 4 years) were recruited for this study (Table 4.1). This sample size was determined *apriori* with a G*Power Analysis for a two tailed paired samples t-test with a moderate effect size of 0.65, an alpha value of 0.05, and power of 80%. Inclusion criteria included full time employment at a childcare center and participants must have worked in their current position for at least three months. The participants included in this study had a range of 1 year to 30 years worked as a childcare educator. Exclusion criteria included a history of knee joint disease or lower extremity injury unrelated to work, and past surgical interventions to the lower extremities. Participants were asked to wear clothing that allows for movement between legs to be seen (i.e., no skirts, overly baggy pants or long shirts), with preference to clothing that also had some visible textures (e.g., jeans). This study received clearance through the University of Waterloo's Research Ethics Board prior to research commencement.

Table 4.1: Participant demographics and anthropometrics.

Age (years)	41.6 ± 10.7
Sex	Female: n = 21 Male: n = 0
Height (m)	1.62 ± 0.11
Mass (kg)	77.0 ± 25.4
Years worked as an educator	12.5 ± 8.3
Age group	Infant: n = 2 Toddler: n = 4 Preschool: n = 15
Dominant leg	Right: n = 19 Left: n = 2
Ethnicity (self-reported)	White: n = 13 South Asian: n = 4 West Asian: n = 1 Black: n = 1

	Latin American: n = 1 Chinese: n = 1

Mean ± Standard Deviation

4.2 Study Protocol

Approximately three to four months prior to research commencement, consultations with childcare educators working in early learning centres were conducted. The childcare educators were recruited through emails to the managers of early learning centres in the Waterloo region, who dispersed the recruitment flyers to the employees where they were invited to join a consultation. During the consultations, we presented our proposed study design to 12 childcare educators, who were then asked questions about whether there would be enough space in their centre to conduct this research, whether there was any aspect of the study design that would make them more or less likely to participate in the actual study, whether they would be willing to help us pilot and champion the study, and if they had any additional questions or concerns. Based on the educators' input at the consultations, the following study design was established.

Twenty-four hours prior to collection, participants were provided with a link to a secure survey system (Qualtrics XM, Seattle, WA). The link directed them to the study consent form and two questionnaires: the Occupational Exposure Questionnaire, and the Investigation for Work-Related Musculoskeletal Disorders Questionnaire (refer to section 4.2.1 for more information about the questionnaires). These questionnaires were used to obtain descriptive information on our study sample, including their perceived high flexion exposure, perspectives on what ergonomic interventions are needed in their field, and descriptions of previous work-related musculoskeletal injuries. As per ethics requirements, participants were allowed to skip any question they did not wish to answer. Participants were instructed to arrive to their place of work 30 minutes before their shift started. Upon arrival the participants were given a brief explanation of what to expect and were given opportunities to ask questions, after which, height and weight measurements were conducted. Participants were asked which leg was their dominant leg. In the case that they were unsure, participants were asked to which leg they would use to complete the following movements: “kicking a ball,” “stomping out a fire,” “picking up a marble,” and “tracing shapes with foot” in order to determine their dominant leg. These movements were chosen for the leg dominance test because these tasks have been previously determined to be the most closely matched with nominated dominant footedness (Schneiders et al., 2010). Next, the participants completed multiple 16-foot walking trials at a self-selected speed in socks, with the force plates located in the second half the walking path (Figure 4.1). The participants repeated walking trials until three successful walking trials for each leg (six total) were completed. A successful walking trial was defined as a trial where the participant’s foot landed entirely on a force plate and the heel of the same foot landed on a second force plate at the end of that stride. The participants were not made aware of this criterion in order to avoid an unnatural gait (e.g., increased or decreased stride length to ensure the foot landed on a force plate). They were only instructed to walk along the path. Due to the limited amount of time before the participants shift started, if we were unable to collect six trials with a full gait cycle, then the trials where the participants entire foot landed on a force plate, defining a good heel strike and toe off for stance phase, were used; this was the case for three participants. After the walking trials, the participants were then instructed to continue their day as usual. At the end of the shift, the participant then completed another round of walking trials with the same instructions as the beginning of the day.

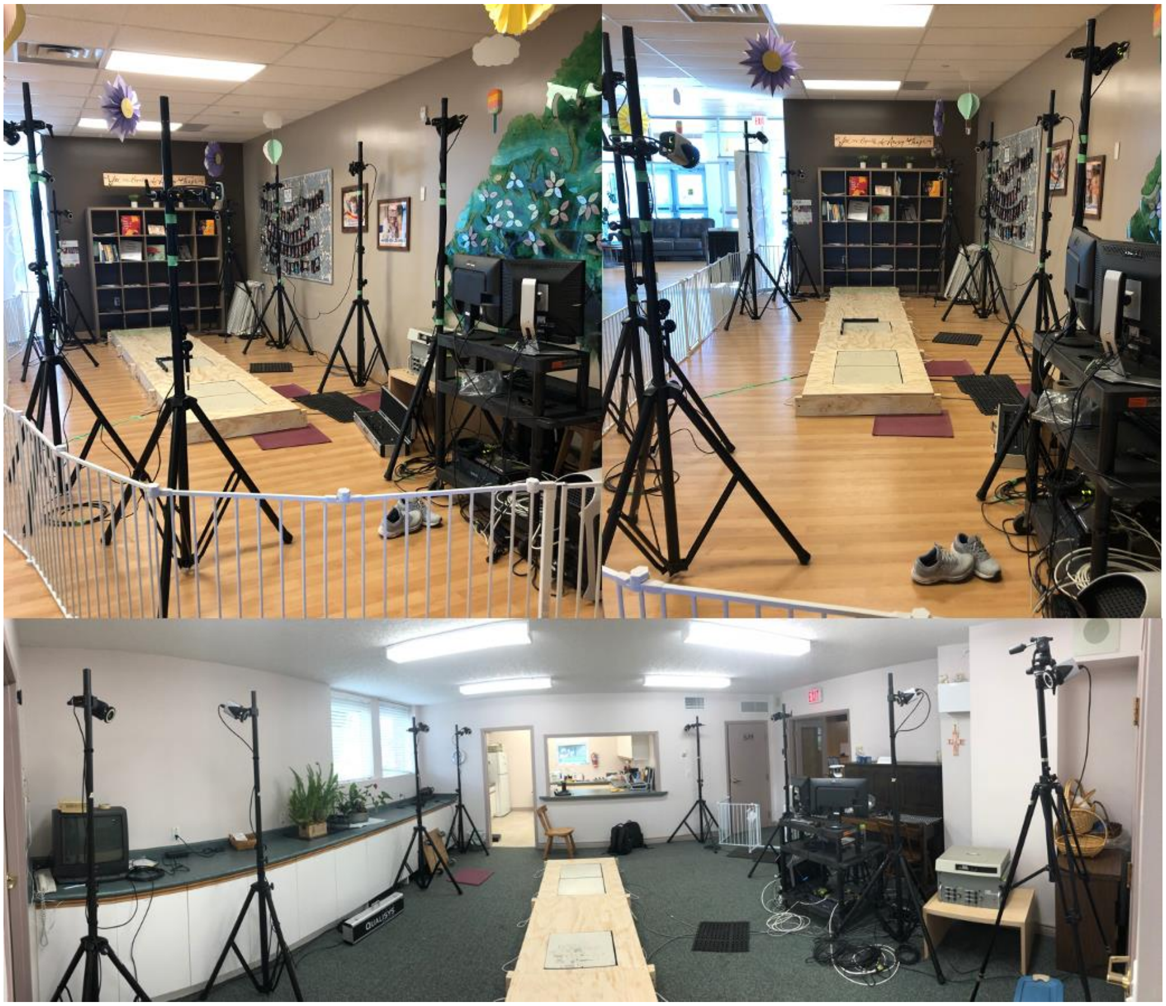

Figure 4.1: The walking platform and camera locations in the two early learning centres.

4.2.1 Questionnaires

Prior to the collection, each participant filled out a questionnaire adapted from the occupational activity questionnaire used by Cooper et al. (1994) and Coggon et al. (2000) (Appendix A.1). This questionnaire asked the participant to reflect on the number of times and the number of total minutes spent lifting, sitting in chairs for adults, sitting in chairs for children, standing, supported and unsupported kneeling, and squatting during a typical day. The participants were asked about many types of activities in order to have the participant think about their entire day and not just about high knee flexion tasks in order to reduce any potential bias.

Participants also filled out a questionnaire that assessed musculoskeletal injury history and perceived ergonomic risk factors. This questionnaire was developed by Cheng et al. (2013) titled Investigation for Work-Related Musculoskeletal Disorders (Appendix A.2). This self-administered questionnaire was designed based on literature evaluating workplace musculoskeletal disorders in health care professionals and childcare educators. For content validity, this questionnaire was revised and approved by four professors specializing in the field of early intervention, rehabilitation science and special education (Cheng et al., 2013). The consensus for the final questionnaire had a content validity index of 0.95 and an interrater agreement of 0.9 (Cheng et al., 2013). This questionnaire provided information on the educators' self-reported musculoskeletal symptoms, work tasks that aggravate the affected region, and their perceived ergonomic needs.

4.3 Motion Tracking

Human motion data was collected using an eight Miqus camera markerless motion capture system (Qualisys, Göteborg, Sweden) at a capture rate of 85 Hz or 60 Hz. At the first early learning centre, data was collected using 85 Hz, but upon arrival at the second centre, a capture frequency of 85 Hz resulted in a strobing effect in the video. In order to have the clearest video possible for Theia3D analysis, the capture rate was decreased to 60 Hz, which eliminated the strobing effect. Calibration and registration of the collection volume was completed by moving a wand with known marker alignment over the walking path until a standard deviation of wand length of 1 mm or less was obtained. The L-frame, used to define the origin and the coordinate system, was placed on force plate one, with the long arm defining the positive X-axis (direction of progression), the short arm defining the positive Y-axis, and the axis pointing upwards as the positive Z-axis (Figure 4.2).

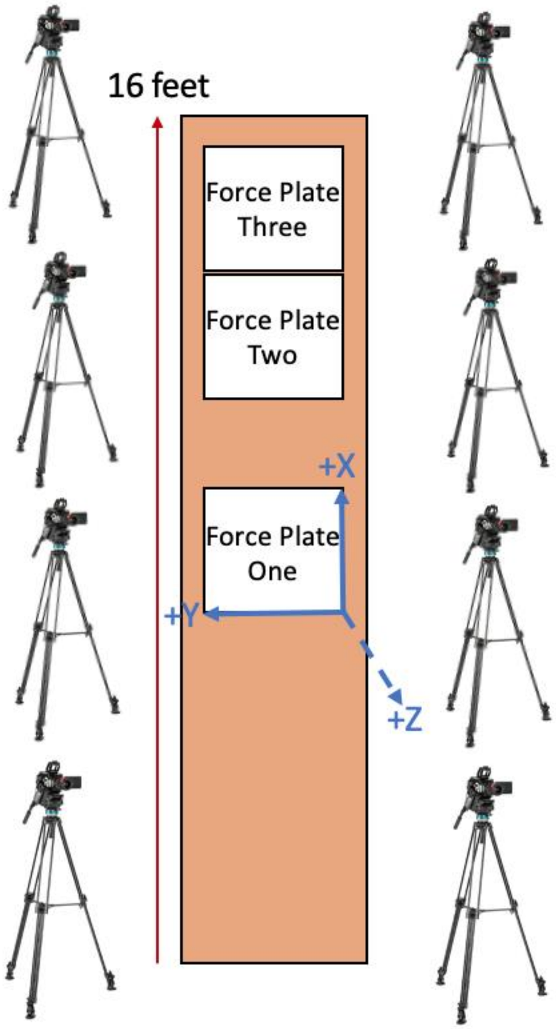

Figure 4.2: A schematic of the eight cameras surrounding the 16-foot walking platform with three embedded force plates, and the global coordinate system on the corner of force plate one.

4.4 Kinetics

Ground reaction forces were collected with three platform embedded AMTI force platforms (Advanced Mechanical Technology Inc., Watertown, MA, USA) at a sampling rate of 1000 Hz and were synchronized with the motion capture data. Force plate amplifiers were left on between participant collections to prevent drift due to temperature (Roriz & Lobo Ribeiro, 2018) and were zeroed each time after calibration of the collection area. Force plate corners of all force plates were located using reflective markers and used for transformations between the force plate, segment, and global coordinate systems.

4.5 Data Processing

Video data and force plate data were collected and synchronized using Qualysis Track Manager (Qualisys, Göteborg, Sweden). The data was then exported to Theia3D (Theia Markerless, Inc., Kingston, ON) for batch processing. Theia 3D software uses deep convolutional neural networks for feature recognition. These neural networks were trained on over 500,000 images sourced from Microsoft COCO (Lin et al., 2015) and a proprietary image set, which was manually labelled by highly trained annotators and controlled for quality by a minimum of one additional expert labeller (Kanko et al., 2021b). The images the algorithm was trained on consisted of humans in a wide range of settings and clothing and had the humans performing various activities (Kanko et al., 2021b). Theia3D extracts the 2D positions of the learned features of the deep learning algorithm, which is then transformed to the 3D space based on the calibration parameters (Kanko et al., 2021b). The local coordinate systems are constructed with their origin at the proximal joint of the segment, the z-axis aligned with a vector from the distal joint of the segment to the proximal joint, and one off-axis feature is used to orient the coordinate system about this axis (Kanko et al., 2021b). Lastly, a multi-body model is then scaled to fit the subject-specific landmark positions and an inverse kinematics approach is used to estimate the 3D pose of the subject throughout the trial (Kanko et al., 2021b). The model pose data for each participant was then brought into Visual3D (C-motion, Germantown, MD) where the data was filtered using a dual pass 2nd order Butterworth low-pass filter at a frequency cut-off of 6 Hz (Winter, 2009). Heel strike and toe off events were identified with a force threshold of 20 N (Tennant et al., 2018; Weeks et al., 2022). The dependent variables of knee flexion angle at heel strike, peak knee adduction angle during stance phase, peak external knee flexion moment during stance phase, and peak external knee adduction moments during stance phase were calculated with a custom pipeline in Visual3D. Joint angles were calculated using a X-Y-Z (flexion/extension – abduction/adduction – axial rotation) Cardan rotation sequence and knee moments were expressed in the tibial coordinate system. Knee angles and moments were time normalized to stance phase duration (Marriott et al., 2019; Tsatalas et al., 2013), with heel strike representing 0% and toe off representing 100% of stance phase.

4.6 Statistical Analysis

The average knee flexion angle at foot contact, peak knee adduction angle during stance, peak external knee flexion moment during stance, and peak external knee adduction moments during stance from the three successful gait trials of each leg at the beginning and end of the shift were calculated. The means from each time point and standard deviations were subsequently calculated. Though this study's hypothesis identifies the expected outcome measurements' direction, there was not enough evidence in the literature to say for sure in which direction these variables would differ (if at all) and therefore a two-tailed paired samples t-test was performed for all outcome variables to test for differences before and after the childcare educators' work shift. Tests for normality and homogeneity of variance were conducted prior to the t-tests and, in the event that a parametric statistical test was not appropriate, a Wilcoxon signed-rank test was performed instead. Effect sizes were calculated using Cohen's *d*, unless a non-parametric equivalent was required, then r was used in its place. Inter-trial error was calculated using the method outlined in Schwartz et al. (2004), to determine whether any individuals experienced a change (post minus pre-shift) larger than that of the natural variability within gait. Additionally, a Pearson Product Moment Correlation was conducted between the amount of change for each outcome variable and the continuous confounding variables to help determine if there is a relationship that can explain the variability of the individual responses. An additional paired t-test was used to compare pre-shift to post-shift gait speed, since some of the outcome measures are known to change with gait speed (Robbins & Maly, 2009; Zeni & Higginson, 2009).

5. Results

5.1 Kinematic and Kinetic Differences Between Pre- and Post-shift Walking Trials

This section includes the results of the pre-post shift t-tests separated by outcome variable. A summary of the results can be found in Table 5.1. Peak knee flexion moment during stance on the non-dominant leg was found to have a statistically significant difference between the pre- and post-shift gait trials. All other variables, for both the dominant and non-dominant leg, had no statistically significant differences before and after the educators' shift. Gait speed was also not significantly different after the occupational childcare shift (t = 1.15, df = 20, p = 0.265, before = 1.14 m/s ± 0.13 m/s, after = 1.15 m/s ± 0.13 m/s, (mean ± standard deviation)].

Table 5.1: Summary of the outcome variables before and after the childcare educators' work shift, comparison results, and their associated effect sizes.

	Before (mean ± SD)	**After (mean ± SD)**	***p*-value**	**Effect size (Cohen's *d*)**
Peak Flexion Moment during Stance (Nm)				
Dominant leg	21.7 ± 11.9	23.0 ± 13.1	0.349	0.209
Non-dominant leg	19.6 ± 12.2	23.6 ± 13.3	0.031*	0.507
Peak Adduction Moment during Stance (Nm)				
Dominant leg	32.6 ± 10.9	33.6 ± 12.1	0.498	0.151
Non-dominant leg^	33.1 ± 13.9	32.3 ± 12.0	0.973	0.011
Flexion Angle at Heel Strike (°)				
Dominant leg	7.3 ± 4.0	7.9 ± 4.2	0.432	0.175
Non-dominant leg	7.8 ± 4.1	8.0 ± 4.2	0.722	0.080
Peak Adduction Angle during Stance (°)				
Dominant leg	6.2 ± 3.2	6.1 ± 3.2	0.813	-0.052
Non-dominant leg	6.5 ± 2.6	6.2 ± 3.0	0.268	-0.249

* $p < 0.05$
^ Statistics calculated using the non-parametric equivalent test: Wilcoxon signed-rank test, effect size (r)

5.1.1 Peak Knee Flexion Moment during Stance

A two tailed paired samples t-test was performed to determine if peak knee flexion moment during stance for each leg was different before and after an occupational childcare work shift. For the dominant leg, the difference was not statistically significant [t = 0.96, df = 20, p = 0.349, before = 21.7 Nm ± 11.9 Nm, after = 23.0 Nm ± 13.1 Nm (mean ± standard deviation)]. For the non-dominant leg, the difference was statistically significant [t = 2.32, df = 20, p = 0.031, before = 19.6 Nm ± 12.2 Nm, after = 23.6 Nm ± 13.3 Nm (mean ± standard deviation)]. There was a small effect size of the shift on the dominant (Cohen's *d* = 0.209) and a moderate effect size on the non-dominant leg (Cohen's *d* = 0.507).

5.1.2 Peak Knee Adduction Moment during Stance

A two-tailed paired samples t-test was run to determine if peak knee adduction moment during stance in the dominant leg was different before and after an occupational childcare work shift. The t-test revealed that the difference was not statistically significant in the dominant leg [t = 0.690, df =20, p = 0.498, before = 32.6 Nm ± 10.9 Nm, after = 33.6 Nm ± 12.1 Nm (mean ± standard deviation)]. For the non-dominant leg, because the Shapiro-Wilk test was significant, the assumptions of normality could not be retained and therefore a Wilcoxon signed-rank test was performed. The Wilcoxon signed-rank revealed that the difference was not statistically significant in the non-dominant leg [V = 114, p = 0.973, before = 33.1 Nm ± 13.9 Nm, after = 32.3 Nm ± 12.0 Nm (mean ± standard deviation)]. After a childcare educator's work shift, there was no statistically significant difference in knee adduction moment on either the dominant leg or the non-dominant leg. There was a negligible effect size of the shift on the dominant and non-dominant leg (Cohen's *d* = 0.151, r = 0.011, respectively).

5.1.3 Knee Flexion Angle at Heel Strike

A two-tailed paired samples t-test was run for each leg to determine if knee flexion angle at heel strike was different before and after an occupational childcare work shift. The t-test revealed that the difference was not statistically significant in the dominant leg [t = 0.80, df = 20, p = 0.432, before = 7.35° ± 3.96°, after = 7.86° ± 4.21° (mean ± standard deviation)] nor in the non-dominant leg [t = 0.36, df = 20, p = 0.722, before = 7.77° ± 4.11°, after = 8.03° ± 4.25° (mean ± standard deviation)]. There was a negligible effect size of the shift on the dominant leg (Cohen's *d* = 0.175) and on the non-dominant leg (Cohen's *d* = 0.079).

5.1.4 Peak Knee Adduction Angle during Stance

A two-tailed paired samples t-test was run for each leg to determine if the peak knee adduction angle during stance was different before and after an occupational childcare work shift. The t-test revealed that the difference was not statistically significant in both the dominant [t = -0.24, df = 20, p = 0.813, before = 6.18° ± 3.24°, after = 6.12° ± 3.18° (mean ± standard deviation)] and non-dominant leg [t = -1.14, df = 20, p = 0.268, before = 6.52° ± 2.63°, after 6.23° ± 2.99° (mean ± standard deviation)]. There was a small effect size of the educators' shift on the non-dominant leg (Cohen's *d* = -0.249) and a negligible effect size of on the dominant leg (Cohen's *d* = -0.052).

5.2 Variability in Response to an Occupational Childcare Shift

Interestingly, there was a lot of variability in the direction of the change and the magnitude of change between participants. Individual pre- and post-shift means for each participant can be found in Figure 5.1. For at least one leg, there were 19 participants who experienced a change greater than the inter-trial error in at least one of the kinetic outcomes and 16 participants in at least one of the kinetic outcomes (Table 5.2). It was not necessarily the same participants who experienced changes across outcome measures or legs.

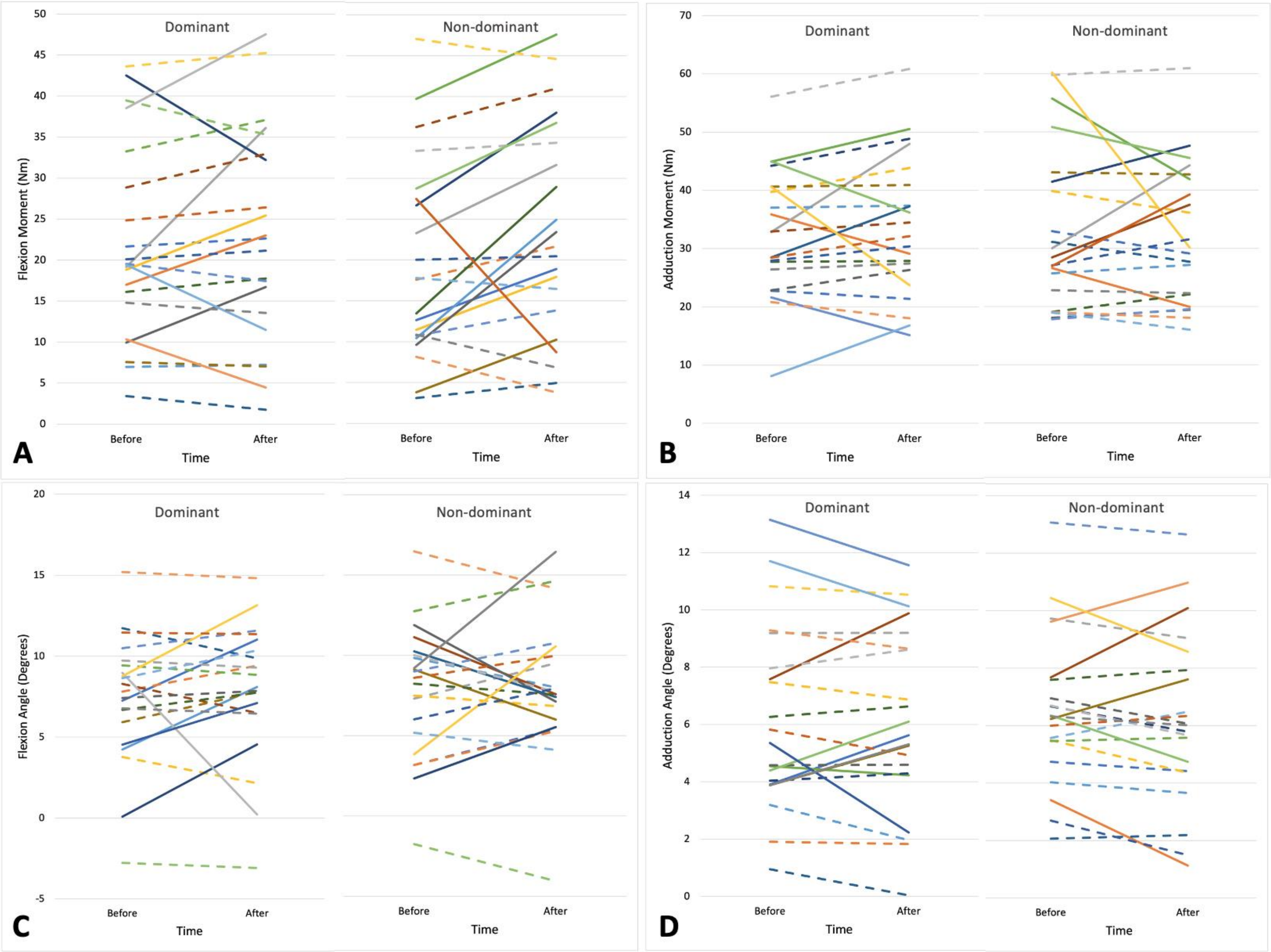

Figure 5.1: Participant differences for A) peak knee flexion moment, B) peak knee adduction moment, C) flexion angle at heel strike, D) peak adduction angle on the dominant and non-dominant leg before and after an occupational childcare work shift. A solid line indicates that the participant experienced a change larger than the inter-trial error for that outcome variable. Participant means and standard deviations are reported in Appendix D.

Table 5.2: Summary of the number of participants who experienced a change larger than the inter-trial error for each outcome variable.

Outcome Variable	**Inter-trial Error**	**Participants who had a change larger than the inter-trial error (/21)**	
		Dominant Leg	**Non-Dominant Leg**
Peak Knee Flexion Moment	5.30 Nm	8	11
Peak Knee Adduction Moment	4.83 Nm	8	8
Knee Flexion Angle at Heel Strike	2.41°	6	7
Peak Knee Adduction Angle	1.25°	8	6

Given the variability in the magnitude and direction of change of the outcome variables that the childcare educators were experiencing, information from the questionnaires were used to try to explain the variability in individual changes. The relationship between the change and continuous variables can be found in Table 5.3. Moderate correlations (Mukaka et al., 2012) were found between peak knee flexion moment in the dominant leg and the self-reported frequency of high knee flexion ($R^2 = 0.4256$) and height ($R^2 = 0.2687$) and between peak knee flexion moment in the non-dominant leg and the duration of standing ($R^2 = 0.3034$). Low correlations (Mukaka et al., 2012) were found in both legs between peak flexion moment and duration of lifting ≥ 10 kg (dominant leg: $R^2 = 0.1373$; non-dominant leg: $R^2 = 0.0968$), peak adduction moment and frequency of high knee flexion (dominant leg: $R^2 = 0.1896$; non-dominant leg: $R^2 = 0.1472$), and peak adduction moment and mass (dominant leg: $R^2 = 0.219$; non-dominant leg: $R^2 = 0.1525$). Additional low correlations in the non-dominant leg were seen between peak knee flexion moment and duration of high knee flexion ($R^2 = 0.1399$), flexion angle at heel strike and age ($R^2 = 0.0934$) and years of service ($R^2 = 0.1755$) and between peak adduction angle and mass ($R^2 = 0.112$). Another low correlation was seen in the dominant leg between peak adduction angle and height ($R^2 = 0.1518$). All other correlations were negligible ($R^2 < 0.09$) (Mukaka et al., 2012).

Table 5.3: Coefficients of Determination (R^2) for the correlation of the participant changes and different continuous variables.

	Peak Flexion Moment		Peak Adduction Moment		Peak Flexion Angle at HS		Peak Adduction Angle	
	Dominant	Non-Dominant	Dominant	Non-Dominant	Dominant	Non-Dominant	Dominant	Non-Dominant
Change in Gait Speed	0.0442	0.0091	0.0021	0.0792	0.0029	0.0027	0.0111	0.0079
Frequency of HKF	0.4256	0.0322	0.1896	0.1472	0.004	0.019	0.0077	0.0753
Duration of HKF	<0.0001	0.1399	0.0595	0.0692	0.0667	0.0201	0.0196	0.0007
Duration of Standing	0.0367	0.3034	0.0429	0.0272	0.0003	0.0815	0.0083	0.0273
Frequency of lifting ≥ 10 kg	0.0283	0.0088	0.0276	0.0003	0.0214	0.0206	0.001	0.0161
Duration of lifting ≥ 10 kg	0.1373	0.0968	0.0259	0.0506	0.0141	0.0105	0.0052	0.006
Age	0.0014	0.0501	0.0001	0.0549	0.0215	0.0934	0.0741	0.0489
Height	0.2687	0.0045	0.0005	0.0006	0.0556	0.0278	0.1518	0.0083
Mass	0.001	0.0241	0.219	0.1525	0.0242	0.0724	0.0343	0.112
Years of service	0.0179	0.0256	0.0605	0.0333	0.0082	0.1755	0.0069	0.0006

Red numbers: moderate correlation; Orange numbers: low correlation

For the categorical variables, the low number of participants in each group did not allow for statistical analysis and made trends difficult to distinguish, especially with the large standard deviations around some means. Figures for the categorical variables can be found in Appendix B. The term “change” is used to describe a change (post minus pre-shift) when taking into account the direction and “absolute change” represents the magnitude of the change, neglecting directionality (increase or decrease).

Collection Weekday

When separating the childcare educators by which day they completed their collection (Monday: n=2, Tuesday: n=2, Wednesday: n=5, Thursday: n=7, Friday: n=5), the middle of the week (Tuesday – Thursday) generally had the largest mean absolute change across all outcome variables and legs, but the overlapping standard deviations indicate that they might not be different from the other days (Figure 10.1).

Age of Children Being Cared For

When separating the childcare educators by the age group of the children they work with (infant: n=2, toddler: n=4, preschool: n=15), peak knee flexion moment in the non-dominant leg had a larger mean absolute change in all categories compared to the dominant leg but there was overlap within the standard deviations in both the toddler and preschool age groups (Figure 10.2A). For peak adduction moment, the infant group had the largest mean absolute change in the dominant and non-dominant legs, but the standard deviations were overlapping with the other age groups (Figure 10.2B).

Ethnicity

When separating the participants based on self-reported ethnicity (White: n=13, South Asian: n=4, West Asian: n=1, Black: n=1, Latin American: n=1, Chinese: n=1), it is not surprising that no discernible trends were identified (Figure 10.3), as only two groups had more than one participant and there was no consistent trend observed between those two groups.

Feet Pain

When assessing for trends with self-reported feet pain, groups were separated two ways: pain (n=13) versus no pain (n=7), and pain separated into categories (no pain: n=7, mild: n=5, moderate: n=5, severe: n=2, unbearable: n=1). When looking at no feet pain versus feet pain, no noticeable differences in any outcome variable was identified, particularly when considering the standard deviations (Figure 10.4). When looking at feet pain with varying levels of severity, it can be seen that the no pain category has the highest change in knee adduction moment, though the standard deviations do overlap with some of the other categories (Figure 10.5B). It is also seen that the unbearable pain group has a much higher change in knee flexion angle at heel strike in the dominant leg compared to the other groups (Figure 10.5C). Lastly, for knee adduction angle in the dominant leg, there appears to be a progressive increase in the amount of change with increasing severity of pain, though the standard deviations do overlap (Figure 10.5D).

Low Back Pain

When evaluating trends by separating the participants by low back pain (no pain: n=4, mild: n=5, moderate: n=6, severe: n=4, unbearable: n=1), no trends were identifiable across all outcome variables, particularly when considering standard deviations (Figure 10.6). The back pain data was not used to separate the participants into pain vs. no pain groups, as was done with feet pain, since there were only four participants that reported no pain.

Knee Pain

The last categorical variable assessed to help explain why certain individuals were experiencing specific changes was knee pain. Similar to feet pain, to evaluate trends in knee pain, participants were separated two ways: pain (n=12) versus no pain (n=8) and by varying levels of severity (no pain: n=8, mild: n=4, moderate: n=6, severe: n=2). When looking at pain versus no pain, there were no identifiable trends in any outcome variable, especially when considering standard deviations (Figure 10.7). When looking for trends based on knee pain categories, the mild pain group non-dominant leg mean absolute change in peak knee flexion moment was higher than all other pain categories (with standard deviations not overlapping), and the mild pain group dominant leg had the lowest mean absolute change, though the standard deviations did overlap with the other groups (Figure 10.8A). When also considering direction of change (increase or decrease), in the dominant leg, there was a trend within peak flexion moment that with increasing pain severity, there was a continual decrease in change, where no pain had the highest positive change and severe pain had the highest negative change, though the standard deviations across groups overlapped (Figure 10.8A). This trend of a higher decreasing change with increasing pain severity is also seen in peak adduction moment in the dominant leg (Figure 10.8B). The last noteworthy trend is the progressive increase in change in knee flexion angle at heel strike with increasing pain severity in the dominant leg, though the standard deviations do overlap across groups (Figure 10.8C).

5.3 Questionnaires

Below are the results from the self-reported questionnaires provided to the participants 24 hours prior to their collection.

5.3.1 Occupational Exposure Questionnaire

The occupational exposure questionnaire evaluated the frequency (number of times performed per shift) and duration (number of minutes during the shift) that the childcare educators perform certain occupational activities that Cooper et al. (1994) and Coggon et al. (2000) has evaluated in association with osteoarthritis development risk. This questionnaire revealed that childcare educators self-reported that they stand (11.5 ± 8.07 times per shift, n=14), lift ≥ 10 kg (9.05 ± 8.65 times per shift, n=19), and squat (6.63 ± 16.77 times per shift, n=19) most frequently during a typical shift (Table 5.4). The childcare educators also reported that they spend the most time during their shift standing (140.87 ± 135.87 minutes per shift, n=15), sitting in a chair appropriate for adults (50.33 ± 53.92 minutes per shift, n=18), and sitting in a chair appropriate for children (40.94 ± 37.73 minutes per shift, n=18) (Table 5.4).

Table 5.4: Summary of Occupational Exposure Questionnaire.

Activity	**Frequency** (times/shift) (mean ± standard deviation)	**Duration** (minutes/shift) (mean ± standard deviation)
Lifting ≥ 10 kg (Frequency: n=19; Duration: n=18)	9.05 ± 8.65	20.44 ± 17.58
Lifting ≥ 25 kg (Frequency: n=19; Duration: n=18)	2.42 ± 4.06	8.5 ± 13.62
Sitting in a chair appropriate for adults (Frequency: n=19; Duration: n=18)	3.47 ± 4.43	50.33 ± 53.92
Sitting in a chair appropriate for children (Frequency: n=19; Duration: n=18)	5.11 ± 5.61	40.94 ± 37.73
Sitting on the floor (Frequency: n=19; Duration: n=18)	5.58 ± 5.85	33.06 ± 24.14
Standing (Frequency: n=14; Duration: n=15)	11.5 ± 8.07	140.87 ± 135.87
Supported kneeling (Frequency: n=18; Duration: n=17)	2.11 ± 1.64	5.76 ± 5.32
Unsupported kneeling (Frequency: n=19; Duration: n=18)	2.95 ± 2.48	11.67 ± 10.80
Squatting (Frequency: n=19; Duration: n=17)	6.63 ± 16.77	9.71 ± 11.79

5.3.2 Investigation for Work-Related Musculoskeletal Disorders Questionnaire

The first portion of the work-related musculoskeletal disorders questionnaires asks the participants about their musculoskeletal pain within the past year. Twenty participants answered this questionnaire. The number of participants that experienced various degrees of pain, the duration of their pain, and how often they experience their pain can be found in Table 0.1 (Appendix C). This questionnaire revealed that a large portion of the participants experience pain on a regular basis. (For this study, a “regular basis” is being defined as an occurrence rate “about once every two weeks” or more frequent). Half of the participants who answered this questionnaire (n = 10), reported that they experienced knee pain on a regular basis. The neck (n = 9), lower back (n = 9), and ankles/feet (n = 9) were tied for the next most common region of childcare educators to experience pain on a regular basis. There was also a high number of individuals who experienced chronic pain (where the duration of symptoms is longer than one month). The most common regions to experience chronic pain were the lower back (n = 7), followed by the knee (n = 6), and lastly the neck (n = 4) and ankles/feet (n = 4). When the childcare educators were asked which region of the body they would consider to be their most affected region, the number one region was the lower back (n = 8), followed by the neck (n = 4) and knees (n = 4), and lastly the shoulder (n = 1), hands/wrist (n=1), upper back (n = 1), and feet/ankles (n = 1). No participant reported the elbow, or thigh as their most affected region.

Since the knee is the region of interest for this study, a deeper dive into the reported knee pain was explored. Within the last year, 13 participants (of 20 participants who answered this questionnaire) experienced pain in the knee ranging from mild pain to severe pain, with moderate pain being most reported (n = 6). The two participants who reported severe pain also reported experiencing this pain approximately every day and that this pain occurs for longer than six months at a time. All six of the participants who reported moderate pain in the knee within the last year also reported experiencing the pain on a regular basis (once every two weeks or more frequently) but the duration of pain varies between greater than six months (n = 3), less than once a month (n = 1), or less than once a week (n = 1) (one participant who reported moderate knee pain in the last year did not answer how long symptoms typically occur). Of the 20 participants who answered this questionnaire, there were four participants who reported the knee to be their most affected region. Of these four participants, three participants reported this region to mildly affect their work performance, and one participant reported that it moderately affects their work performance. One participant is considering a job change as a result of their knee pain and is seeking treatment.

The next group of questions in this questionnaire asked participants to report if they experience any musculoskeletal injury symptoms (i.e., pain) during specific work tasks. A summary of the number of participants that experience pain in certain regions of the body due to specific work tasks can be found in Table 0.2 (Appendix C). The top three tasks that the educators reported experiencing the most musculoskeletal injury symptoms on various locations around the body were diaper changing, transferring, and toileting. The most common region reported to experience musculoskeletal injury symptoms during diaper feeding was the lower back (n = 8); during transferring was the shoulder (n = 5); and during toileting was the lower back (n = 5).

The last question of this questionnaire asked the participants to self-report on which intervention they believe is needed to reduce the number of musculoskeletal injuries and pain that occurs in occupational childcare. A summary of the number of participants that ranked five different interventions as needed (score of 4 or 5) or not needed (score of 1 or 2) can be found in

Table 0.3 (Appendix C). Three interventions (environmental modifications, postural education, and muscle strengthening) were reported by at least 45% of the study sample as needed (Figure 5.2). Work-time adjustment had equal numbers of participants (30%) reporting this intervention as needed or not needed, with 40% responding as neutral. Over half the study sample reported that they were neutral towards knowledge on use of personal protective equipment (timing for the use of lumbar supports, knee braces, etc.).

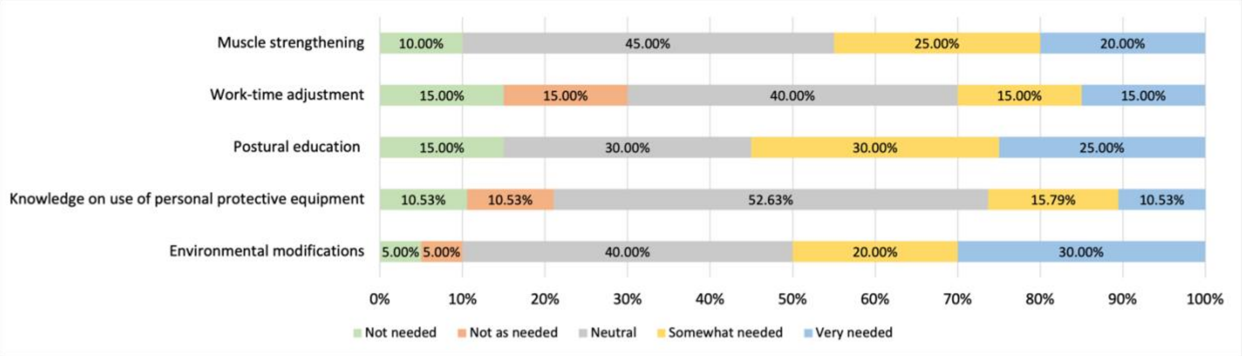

Figure 5.2: Percentage of individuals that ranked the necessity of each potential intervention.

6. Discussion

The study presented in this thesis compared knee flexion angle at foot contact, peak knee adduction angle during stance, peak knee external flexion moment during stance, and peak knee external adduction moment during stance before and after a childcare educator's work shift. This study and its findings allow us to have a better understanding of whether a single bout of the daily activities the educators are performing in their workplace has an impact on knee outcomes associated with musculoskeletal injuries. The hypothesis that there would be an increase in all outcome variables at the end of the day compared to the beginning of the day was partially supported as there was a statistically significant increase in peak knee flexion moment in the non-dominant leg but there was no other statistically significant difference for any other dependent variable on either leg.

Previous research has shown that as little as 30 minutes of cumulative kneeling exposure or greater than 30 instances of high knee flexion positions during a working shift for over one year is associated with an increased risk of lower limb musculoskeletal injuries (Coggon et al., 2000; Cooper et al., 1994; D'Souza et al., 2008; Jensen, 2008). To understand why this association may occur, other studies (Kajaks & Costigan, 2015; Tennant et al., 2018; Weeks et al., 2022) have examined knee mechanics during gait after a 30-minute kneeling exposure protocol and have found changes similar to those seen in individuals with knee osteoarthritis and other related musculoskeletal injuries. During half of a childcare educator's shift (approximately 3.3 hours), it has been found that childcare educators spend an average of 1.57 hours, 1.55 hours and 1.24 hours in high knee flexion when caring for infants, toddlers, and preschool aged children respectively (Laudanski et al., 2022). The amount of time the childcare educators have been reported to spend in high knee flexion during half a shift is longer than the amount of time shown to cause changes in knee mechanics, leading one to speculate that there may be similar changes after an 8-hour occupational childcare shift where the chances of longer cumulative high knee flexion exposure is likely. However, given that there was only one statistically significant difference after the occupational childcare shift in the outcome variables that have been shown to change in previous studies evaluating gait differences after varied 30-minute kneeling exposure protocols, there is a need to look at whether the same changes occur in protocols that reflect the work done by the occupation of interest (i.e., 8-hour collection with high knee flexion spaced throughout the protocol). It is possible that there were acute changes immediately after short-term instances of high knee flexion performed by the childcare educators, but the pre-post shift study design did not allow for the capturing of those changes. Future studies should potentially consider adding multiple collections throughout the day, however, one should remain cautious about the number of interuptions to the childcare educators work shift.

Gaudreault et al. (2013) examined knee kinematic differences between individuals in non-knee straining occupations and those in knee straining occupations. This study demonstrated significant kinematic differences between the two groups, with the difference in the individuals in the knee straining occupations reflecting both the kinematics seen in those with musculoskeletal ailments (section 2.2.2 to 2.2.5), and the changes seen with prolonged kneeling (section 2.2.1). While the current study showed that these changes are not seen after a single occupational childcare shift, there may be minute changes in variables that were not assessed during this study that over time lead to the change in knee mechanics. For example, Garcia et al. (2015) evaluated muscle fatigue after five hours of standing work, that included seated rest breaks and a 30 minute lunch. Garcia et al. (2015) found that muscle fatigue was strongly present at the end of the work day and persisted beyond 30 minutes after the work day. Given that the childcare educators of this study have self-reported that they spend the most time during their shift standing (Table 5.4), it is plausible that they are experiencing muscle fatigue, which although may not change their knee mechanics after a single day, could potentially be playing a cumulative role and lead to changes in the future.

While this study only demonstated a significant difference in peak knee flexion moment in the non-dominant leg, there were many participants who experienced a meaningful change in the other outcome variables (Figure 5.1). Since there is currently no agreed upon threshold beyond which a knee joint moment change is considered meaningful, particularly within healthy control participants, this study defined a meaningful change in each outcome variable as a change larger than the inter-trial error for the associated variable. For adduction/abduction angles, the inter-trial error calculated from the current study's participant data was 1.25° which fell within the previously reported values of 0.1° to 1.6° (Kanko et al., 2021b; Kaufman et al., 2016; Manca et al., 2010; Schwartz et al., 2004). The flexion/extension angle inter-trial error value was 2.41° which is slightly higher than those previously reported at 1.6° to 2.2° (Kanko et al., 2021b; Kaufman et al., 2016; Manca et al., 2010; Schwartz et al., 2004). The knee moments inter-trial errors for adduction/abduction (4.83 Nm) and flexion/extension (5.30 Nm) were also within the range of previously reported inter-trial error of knee moments (<8 Nm) (Fortin et al., 2008). Using these inter-trial error values as thresholds, it was seen that 11 participants had a meaningful change in peak knee adduction angle (three in both legs, five in just the dominant leg, three in just the non-dominant leg), 11 participants had a meaningful change in knee flexion angle at heel strike (two in both legs, four in just the dominant leg, five in just the non-dominant leg), 11 participants had a meaningful change in peak knee adduction moment (five in both legs, three in just the dominant leg, three in just the non-dominant leg) and 15 participants had a meaningful change in peak knee flexion moment (four in both legs, four in just the dominant leg, seven in just the non-dominant leg). While all these changes were defined as meaningful, the direction of change was variable across the participants leading into a further analysis of why certain people may be experiencing a change and others are not, as well as what might be influencing the direction of change.

6.1 Occupational Exposures

Some of the physical occupational exposures that may have an influence on the amount of change in knee mechanics during gait a childcare educator experiences after a shift include frequency and duration of high knee flexion, duration of lifting a weight greater than 10 kg, and duration of standing. The frequency of high knee flexion displayed a moderate positive correlation with peak knee flexion moment change in the dominant leg and a low positive correlation with peak knee adduction moment change in both legs (Table 5.3). The duration of high knee flexion also had a low positive correlation with peak knee flexion moment in the non-dominant leg (Table 5.3). Greater than 30 minutes of high knee flexion or greater than 30 instances of high knee flexion within an 8-hour work shift has been associated with a higher risk of developing knee osteoarthritis (Coggon et al., 2000; Cooper et al., 1994) and individuals with musculoskeletal ailments of the knee have been shown to have increased peak knee flexion moment and knee adduction moments (Baliunas et al., 2002; Na et al., 2018; Rudolph, Schmitt, & Lewek, 2007; Tsatalas et al., 2013). The correlations presented in this thesis demonstrate that an increase in the frequency and duration of high knee flexion are correlated with an increase change in peak knee flexion moment and peak adduction moment, which potentially could be putting the childcare educators at risk for musculoskeletal ailments of the knee in the future.

The duration of lifting greater than or equal to 10 kg also had a low positive correlation with peak flexion moment in both legs (Table 5.3). Like high knee flexion, lifting greater than or equal to 10kg has been described to have an odds ratio of 1.7 (95% confidence interval: 1.2-2.4) for developing knee osteoarthritis if performed over 10 times per week (Coggon et al., 2000). While the same lifting thresholds were not used, there does appear to be a similar relationship between the duration of lifting the weight and the change in knee flexion moment, which may be putting the individuals at an increased risk for developing musculoskeletal ailments.

Lastly, the duration of standing was shown to have a moderate positive correlation with changes in peak knee flexion moment (Table 5.3). Prolonged standing has been shown to place high loads on the hips, knees, and ankles and reduces the normal lubrication and cushioning of the joints (Miller et al., 2015; OSH, 2020). Standing or walking for greater than 2 hours per day has also been shown to have an odds ratio of 1.5 (95% confidence interval: 0.8-2.9) for developing knee osteoarthritis (Coggon et al., 2000). The exposure variables reported in the current study were assessed through self-reported questionnaires asking about a typical workshift. Future research should further investigate these correlations to see if they persist or are strengthened when exposure is measured objectively (i.e., through wearable sensors) and on the actual day the outcome measures are being assessed rather than a “typical day.”

6.2 Influence of Height, Mass, Age, and Years of Service on Knee Mechanics

There appears to be an influence of demographic variables on the amount of change in knee mechanics childcare educators experience after an occupational childcare shift including height, mass, age, and years of service. Height had a moderate positive correlation with a change in peak flexion moment in the dominant leg and a low positive correlation with a change in peak adduction angle in the dominant leg (Table 5.3). Individuals who are taller, may require more time bending down to interact and play with the children, and when sitting in a chair meant for children, it may require more bending of the knees due to longer legs. Acute bouts of high knee flexion have been shown to cause changes in knee mechanics (Kajaks & Costigan, 2015; Tennant et al., 2018; Weeks et al., 2022) and with the assumption that taller individuals need to bend more to interact with the children, this positive correlation is not surprising.

Mass had a low negative correlation with a change in peak adduction moments in both legs and a low negative correlation with a change in peak adduction angle in the non-dominant leg (Table 5.3). Individuals with higher body weight have been shown to walk slower with shorter and wider steps and with a greater toe out angle (Runhaar et al., 2011), all of which has been shown to reduce knee adduction moments and angles (Robbins & Maly, 2009; Uhlrich et al., 2018). The negative correlations between mass and a change in frontal plane mechanics suggest that the heavier individuals may continue to decrease their speed (although not significantly so in the current study) or adapt an even greater toe out angle by the end of their occupational childcare shift, decreasing their frontal plane mechanics. Unfortunately, it is currently not possible to assess the toe out angle of the participants in the current study as individual landmarks used to define toe out angles were not tracked and markerless motion capture estimates the segment pose but not the coordinates of specific bony landmarks.

Both age and years of service had a low positive correlation with flexion angle at heel strike in the non-dominant leg (Table 5.3). Previous research has demonstrated age-related degeneration in the control of the lower limb trajectories during walking (Begg & Sparrow, 2006) including reduced eccentric electromyography burst duration and impaired swinging leg balance control during gait (Jeon et al., 2023). The correlation suggests that after a shift of occupational childcare, there may be additional instability and muscle control resulting in an increased change in flexion angle at heel strike in the older educators compared to the younger educators.

6.3 Occupational Exposure vs. Demographic Relationship with Knee Mechanics

Interestingly, the exposure variables above (duration and frequency of high knee flexion, duration of lifting, and duration of standing) had only negligible correlations with the kinematic outcome variables, whereas the demographic variables above (height, mass, age, and years of service) did display some correlation with the kinematic outcome variables (Table 5.3). Febrer-Nafría et al. (2023) demonstrated that knee kinematics are primarily determined by static alignment, whereas knee kinetics are primarily determined by muscle coordination strategy. This indicates that the exposure variables may have some underlying mechanisms, such as causing muscle fatigue (Garcia et al., 2015; Jung et al., 2010), leading to the changes in knee kinetics during gait whereas demographic variables, such as age and weight may have an impact on the supporting structures of the knee (Noyes & Grood, 1976) and effect static alignment. Future research should consider assessing other mechanisms that may be influencing the change in knee mechanics such as changes in muscle activity after a day of work, differences in static alignment, and a change in their foot progression angle as all these factors have been shown to contribute to differences in knee angles and moments during gait (Fujita et al., 2021; Hurwitz et al., 2002; Nagura et al., 2017; Seagers et al., 2022; Simonsen, 2014).

6.4 Additional Confounding Factors on Knee Mechanics

This study also looked at trends within other confounding variables including the day of the collection, age group of children, ethnicity, and pain. When considering the day of the collection, the day the collection was on did not appear to have an effect on the magnitude of change as the standard deviations from all the days were large and overlapped with the other days (Figure 10.1). Previous research has shown an effect of day in muscle fatigue measures as fatigue accumulated throughout the workweek due to incomplete recovery over consecutive days (Yung, 2016). While this does not appear to be the case for the reported knee mechanics measures during gait, even though it has been seen that muscle fatigue can affect knee joint moments (Kellis, 1999; Zhang et al., 2022), the absence of a similar trend could be due to a difference in study design as we are not measuring the same participants over multiple days, or due to the difference in the group size between days. Future research should consider investigating if there is a cumulative change in knee mechanics in the same participant over the workweek, and whether there are similar amounts of change after a shift between days. When separating the participants by the age group of children they cared for, the group of participants working with infants had the largest mean absolute change in peak adduction moment, though the standard deviations did overlap with the other groups (Figure 10.2). Laudanski et al. (2022) found that educators working with infants spent the most time in high knee flexion and transitioning into and out of high knee flexion compared to the educators working with toddlers and preschool aged children. Since acute bouts of prolonged kneeling have been shown to cause changes in knee adduction moment (Kajaks & Costigan, 2015; Tennant et al., 2018; Weeks et al., 2022), it is not surprising that the group that has been shown to spend the most time in high flexion would have the largest change in knee adduction moment. However, as the current study only had two participants in the infant group, future studies should continue to investigate this and strive to have an equal number of participants in each group.

Another confounding variable that was assessed for trends in the changes in gait mechanics was ethnicity. Research has shown that there are knee mechanics differences during gait between people with different ethnicities (Hill et al., 2020; Leszko et al., 2011; Sims et al., 2009), however, this study does not indicate any trends in the amount of change individuals of different ethnicities experience after a childcare shift (Figure 10.3). Therefore, while there is evidence of different gait mechanics between groups, there does not appear to be a difference in the amount of change each ethnicity experiences after a shift. However, there is a very low number of individuals in most ethnic groups (i.e., four ethnic groups only had one participant in the group) making it challenging to draw conclusions.

The last categorical confounding variable that was assessed was pain in the feet/ankle, knees, and lower back. While there were a few noticeable differences between pain severity groups, the large and overlapping standard deviations between groups makes it difficult to identify conclusive trends. The lack of noticeable trends could be related to the low sample in each group, but it may also be related to a variety of avoidance behaviours in individuals with a history of pain (Vandael et al., 2023). Individuals with a history of pain may have learnt which activities trigger their pain and therefore avoid them all together, they may also perform these activities but in a modified way, or they may just experience chronic pain all the time and therefore just continue all their daily tasks as usual, leading to a large variability of change within the same pain group. Another thing to note is that while we did ask the participants about this history of pain in the feet and knees, we did not ask them which limb they are experiencing their pain in, so while they may be in an “unbearable” pain severity group, their dominant or non-dominant limb might not be the limb that they would consider having “unbearable” pain in, making it challenging to notice trends. While nothing conclusive about pain severity and its relationship with change in knee mechanics can be drawn from the trends in this study, future research should continue to evaluate changes in knee mechanics during gait in individuals with different pain severities.

6.5 Measuring High Knee Flexion Exposure in Occupational Childcare

To understand the occupational exposures in childcare work and to provide descriptives for our study sample's experience with musculoskeletal exposures in their workplace, the participants of this study were asked to answer an occupational exposure questionnaire that was based off the activities performed in childcare settings and those assessed in Cooper et al. (1994) and Coggon et al. (2000). Cooper et al. (1994) established that jobs that entail more than 30 minutes per day of squatting or kneeling had odds ratios of 6.9 (95% CI 1.8-26.4) and 3.4 (95% CI 1.3-9.1) for knee osteoarthritis development respectively. In only half a shift, Laudanski et al. (2022) observed with video data that, on average, childcare educators spend greater than 1.24 hours in high flexion, and experience greater than 113 instances of high knee flexion postures. When asking the childcare educators of this study about instances of high knee flexion postures, the activities of sitting in a chair appropriate for children, sitting on the floor, supported kneeling, unsupported kneeling, and squatting were included because getting into these positions requires the knees to be in high flexion (Laundanski et al., 2022). The childcare educators (n=19) self reported 22.26 ± 21.50 (mean ± standard deviation) instances of high knee flexion in a typical shift. When asking about duration of high knee flexion postures, the activities of child chair sitting, unsupported kneeling, and squatting were included at as maintaining these postures require the knees to be in a high flexion posture. The childcare educators (n=18) self reported (mean ± standard deviation) minutes of high knee flexion during a typical shift. Both the number of instances and the duration spent in high flexion is much smaller than the observations reported by Laudanski et al. (2022) during a half shift. This disparity could be attributed to the different facility which may have a different environment and work policies, or it is possible that the childcare educators are under reporting, based on the fact that the higher numbers in Laudanski et al.'s (2022) study were based on direct (video) observation. However, the average self-reported values still put the childcare educators above the 30 minutes of high knee flexion threshold that has been associated with an increased risk of knee osteoarthritis development (Coggon et al., 2000; Cooper et al., 1994; D'Souza et al., 2008; Jensen, 2008). Additionally, the large standard deviations of this questionnaire's results demonstrate that there is large variability in the self-reported outcomes, indicating some concerningly high self-reported exposures for some educators, and highlighting the need to get a direct measure of exposure.

Initially, this study planned to use inertial measurement units (IMUs) to quantitatively measure exposure during the childcare educators' shift. Pilot work was done both on campus and within one of the early learning facilities to ensure this was feasible, however, upon collecting within the childcare centres many challenges were presented including battery life issues, connectivity to the reciever when collecting data from more than one participant or where the wifi signal was minimal, and delays in data storage. In-field trouble shooting adressed many of these issues, however the quality and quantity of data we were able to collect were still seriously affected and lead to the decision to remove the IMU exposure measure from this thesis and instead rely on quantifying exposure through self-reported questionnaires. Self-reported questionnaires do have potential for participants to not accurately recall events, and have been shown to result in participants over- or underestimating their amount of exposure (Ács et al., 2020; Nelson et al., 2019). Had the IMU exposure data been of good quality and quantity, it would have allowed for a more accurate representation of how much knee flexion childcare educators are experiencing within their shift and would have allowed for a better understanding of whether those that do more high knee flexion within their workshift experience a larger change or a specific direction of change within the outcome variables of gait. Future studies should consider using an objective measure of exposure rather than relying on self-reports, such as through IMU sensors that store the data onto the device which would help ensure better quality and quantity of data as it avoids connectivity issues and would help with battery life (Schall et al., 2022).

While the results of this study demonstrate that an occupational childcare shift does not result in a statistically significant change in the knee mechanics of the workers, with the exception of knee flexion moment in the non-dominant leg, the number of educators in this study that reported the knee to be one of the top locations to experience musculoskeletal injury symptoms (i.e., pain) as a result of their daily work activities, demonstrates the need for more research in this area. Previous studies (Burford et al., 2017; Rasmussen et al., 2020) have modified certain aspects of diapering, feeding, toileting, grooming, and transferring, however saw no significant changes to the musculoskeletal injuries in childcare educators. In the current study, the childcare educators ranked the knee as one of the regions least affected by these five work tasks, therefore there may be more success with more research into which activities, positions, or cumulative exposure are causing this knee pain. Future research may also consider assessing if there are specific parts of the day that may have more effect on the loading of the knee joint and whether the knee recovers during times of rest, such as with lunch breaks and nap times. To understand the cumulative effects of the daily activities done by childcare educators on their knees, one may also consider conducting a long-term follow up study with the same participants and see if their baseline knee biomechanics are different from the baseline measurements in the current study. We also do not know for certain the order in which the kinematic and kinetic variables change. The variables chosen for this study are variables that have been found to be different in individuals with knee osteoarthritis, however it is not known if these changes happen before or after osteoarthritis development. Future studies may want to consider other changes, such as muscle fatigue, that may be occurring within a single day, that may potentially lead to gait kinematic and kinetic changes in the future.

7. Limitations

The protocol used in this study is limited in that it only assessed differences after one working day. Participants were asked at the end of the workday if the tasks they performed that day are a good representation of what is done on a typical workday, and, if not, to describe what part(s) of the day were atypical. Most participants said their day was typical, but there were two participants who said that while it may have been typical in terms of physical workload, it was not typical given that they had scheduled programing. For example, one class made lemonade from different recipes in the afternoon, rather than letting the children freely choose activities as they would throughout the day. The educator described scheduled programming as more mentally exhausting. We are not certain that the amount of high knee flexion exposure that they may partake in on a typical day is the same amount that they would experience with scheduled programing.

Next, there are currently no thresholds defining a meaningful difference in peak knee adduction moment, peak knee flexion moment, peak knee adduction angle, and knee flexion angle during heel strike in healthy individuals as there are currently no studies, to my knowledge, that indicate whether there are any kinetic or kinematic gait changes that occur prior to musculoskeletal ailment initiation. Therefore, meaningful differences were defined as a change larger than that of normal variability of gait (inter-trial error). Though we currently cannot be certain that this change would have clinical meaning in predicting the development of musculoskeletal ailments, regular changes in knee mechanics after every shift (over months or years) may place additional loads on the knee joint making individuals more susceptible to musculoskeletal ailments later in life.

This study also used self-reported questionnaires to get a general view of the activities/positions childcare educators engage in on a typical day and musculoskeletal injuries in the workplace. Self-reported questionnaires have the potential for biases including recall bias where the participants do not accurately remember previous events, and participant bias where the participant fills out the questionnaire based on what they think the researcher wants to hear based on the study description (Althubaiti, 2016). As directed by ethical research practices, we allowed any participant to skip any questions they did not wish to answer as these questionnaires were used only for secondary (descriptive/explanatory) information for this study. Both the bias and missed questions may have resulted in an imprecise representation of the childcare educators' movement exposure and musculoskeletal injuries, and this is reflected in the inconsistencies both within the participants reports and the large standard deviation of educators' responses. Future studies should consider measuring exposure objectively (i.e., through sensors such as IMUs as discussed previously) rather than relying on self-reported questionnaires; however, the questionnaire results did allow for a preliminary understanding of why the observed changes in the childcare educators' knees occurred and provided guidance on whether exploring this area more in the future would be of value.

Another limitation is this study is the small sample size. Though this study reached the sample size that was determined *apriori* based on the effect sizes from data in published literature (Gaudreault et al., 2013; Weeks et al., 2022), a post-hoc power analysis using the current study's largest effect size revealed a suggested sample size of 33 participants and should be considered as the sample size for future studies with similar objectives and statistical tests. Additionally, a larger sample size for this study would have been beneficial when evaluating potential explanatory variables for individual responses to the childcare shift. Many of the categorical explanatory variables had only one participant in certain groups (e.g., ethnicity, pain severity) and a larger sample size could have allowed for more individuals to be allocated to these groups and allowed for more confidence in the trends seen within the explanatory variables. Additionally, more participants would have allowed for the conduction of a multiple linear regression to investigate the relationship of the changes in the outcome variables, when multiple confounding variables are being considered.

8. Conclusions and Contributions

The results of this study suggest that a single occupational childcare shift does not result in statistically significant differences in childcare educators' biomechanical knee outcomes that have been associated with musculoskeletal ailments, except for the peak knee flexion moment on the non-dominant leg. However, the majority of participants experienced a change in one or more of the outcome variables larger than the natural variation in the measurement. This finding indicates that some other factors, beyond natural variability, are likely contributing to the changes observed.

In addition, this study also established baseline values that can be used in future longitudinal studies assessing whether working in occupational childcare impacts knee biomechanics overtime. Using the data collected from this study and comparing it to the same educators' gait data in a study two to three years from now, for example, would allow for information on the longer-term impacts of working in occupational childcare.

This study also proved the feasibility of collecting data within an early learning centre. Since childcare educators work in a facility filled with children, data collection protocols must be sensitive to this fact, and must address concerns from parents regarding the privacy of their children, time constraints placed on educators immediately before or after shifts, protecting expensive equipment, and obtaining sufficient space to collect this data. However, with the input from educators both in the development of the study and during its operations, we have addressed any concerns and challenges, and then proved that collecting kinematic and kinetic data before and after a work shift within the childcare facility is feasible.

This study provided information on the physical effects of occupational childcare in female participants. With the exception of nursing, literature on the physical effects of jobs in female dominated occupations are sorely lacking. This study adds information on what changes females may be experiencing after working a shift in an occupation that requires high knee flexion. This thesis does provide baseline and after work values that can be compared to the physical effects of other female dominated occupations and help expand the diversity of the literature.

Lastly, while not a primary objective of this study, the questionnaires of this study also provide very enlightening information regarding the amount of pain, regions of pain, and which interventions the educators believe would be the most successful in their place of work. The childcare educators have reported the neck and knee to be tied for the second most affected region, however the knee was one of the regions least affected by the tasks that were previously classified as the five major work tasks required in occupational childcare. These tasks were modified in the work by Burford et al. (2017) and Rasmussen et al. (2020) but saw little to no changes in musculoskeletal injuries in childcare educators. The results from this study's questionnaires indicate that it may be worthwhile to investigate and modify other portions of the educator's workday that may be contributing to the high reports of knee pain. These questionnaires also identified which interventions the childcare educators believe are most needed, which were environmental modifications, postural education, and muscle strengthening. Interventions within these categories are more likely to be successful since they are areas the educators believe are necessary and therefore will be more likely adhere to long term.

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Appendices

Appendix A: Questionnaires

Appendix A.1: Occupational Exposure Questionnaire (devised based on studies that evaluate occupational activities associated with the development of osteoarthritis (Coggon et al. (2000); Cooper et al. (1994))

Participant ID:_________________________ Date: ______________________

OCCUPATIONAL HIGH KNEE FLEXION EXPOSURE QUESTIONNAIRE

The following questionnaire will ask you to reflect on how many times on a **typical day** of work do you engage in each of the following occupational activities and for how long.

Activity	Frequency (number of times/day)	Duration (minutes/day)
Lifting ≥ 10 kg (22 lbs) [a]		
Lifting ≥ 25 kg (55lbs) [b]		
Sitting in a chair appropriate for adults		
Sitting in a chair appropriate for children		
Sitting on the floor		
Standing		
Supported kneeling (Figure 1.A)		
Unsupported kneeling (Figure 1.B)		
Squatting		

[a] The average 2-year-old will weigh approximately 12 kg (26.4 lbs). (WHO, 2006)
[b] An overweight 4-year-old will weigh approximately 25 kg (55 lbs). (WHO, 2006)

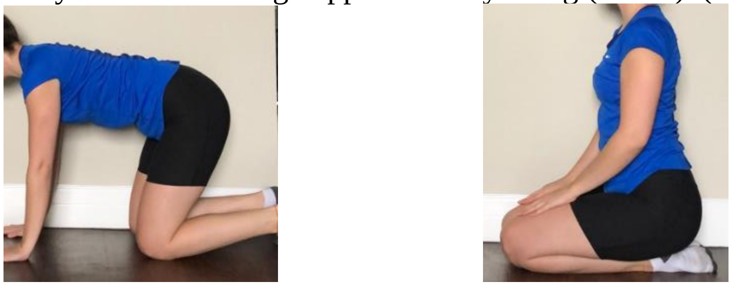

Figure 1: A) Example of Supported Kneeling; B) Example of Unsupported Kneeling

Appendix A.2: Investigation for Work-Related Musculoskeletal Disorders Questionnaire (adapted from Cheng et al. (2013))

MUSCULOSKELETAL SYMPTOMS

Note: Check the appropriate box

Has any of the following occurred within this year?

Symptom	Region	Neck	Shoulder	Elbow	Hands and/or Wrist	Upper Back	Lower Back	Thighs	Knee	Feet and/or Ankles
Severity	No pain									
	Mild pain									
	Moderate pain									
	Severe pain									
	Unbearable pain									
Duration of symptoms	< 1 week									
	< 1 month									
	1-3 months									
	3-6 months									
	> 6 months									
Occurrence rate	Almost everyday									
	About once a week									
	About one every two weeks									
	About once a month									
	About once a year									

Check the most affected region (Please tick only one box)

☐ Neck ☐ Shoulder ☐ Elbow ☐ Hand or Wrist ☐ Upper Back ☐ Lower Back ☐ Thigh ☐ Knee ☐ Ankle or Foot

Please answer the following questions in relation to your most affected region

1. **How does this region effect your work performance?**

a. Not affected
b. Mildly affected
c. Moderately affected
d. Severely affected
e. Cannot work

2. Does this region cause you to take sick leaves?
a. Yes
b. No

3. Are you seeking any treatments for the affected region?
a. Yes
b. No

If answered yes, which treatments?

4. Are you considering a job change as a result of your affected region?
a. Yes
b. No

ERGONOMIC FACTORS

Note: Check the appropriate box

Work Task	**Region with Symptoms**									
	Task execution	Neck	Shoulder	Elbow	Hand and/or Wrist	Upper Back	Lower Back	Thigh	Knee	Foot and/or Ankle
Diaper changing	☐ Yes ☐ No									
Feeding	☐ Yes ☐ No									
Toileting	☐ Yes ☐ No									
Grooming	☐ Yes ☐ No									
Transferring	☐ Yes ☐ No									

Ergonomic Needs

	1 **Not Needed**	**2** **Not as Needed**	**3** **Neutral**	**4** **Somewhat Needed**	**5** **Very Needed**
Environmental modifications (Such as size and heights of tables, chairs, etc.)					
Knowledge regarding the use of personal protective equipment (Timing for the use of lumbar supports, knee braces, etc.)					
Postural education (Proper body mechanics, child handling techniques, etc.)					
Work-time adjustment (Such as ways to arrange the work and break time)					
Muscle strengthening (Frequency, intensity, and duration)					

~ Thank you for your participation ~

Appendix B: Relationships between the change in outcome variables and potential explanatory variables

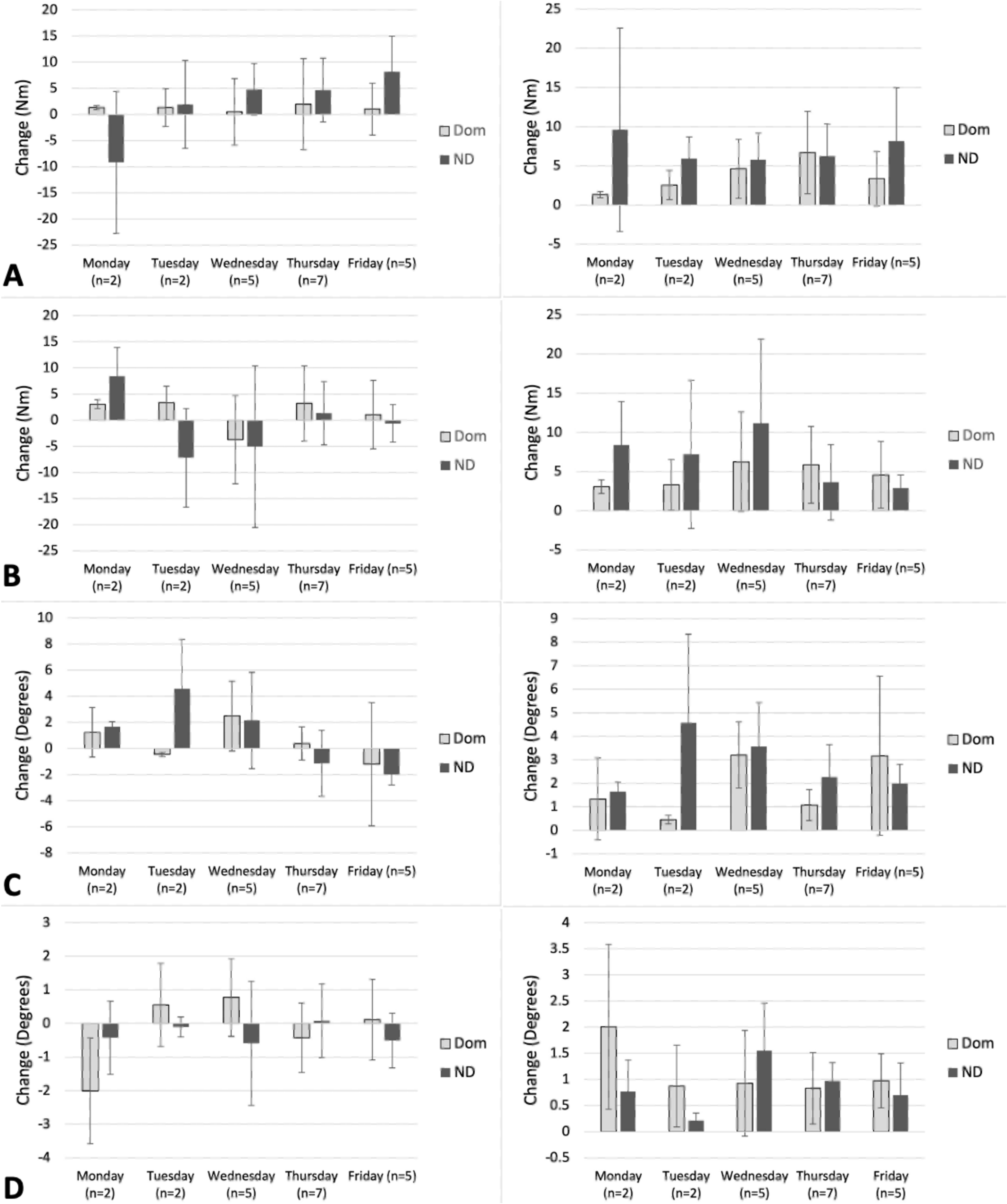

Figure 0.1: Mean and standard deviations of change (change on the left and absolute change on the right) for the participants when separated into groups based on the day their data was collected. A) Peak knee flexion moment, B) peak knee adduction moment, C) knee flexion angle at heel strike, D) peak knee adduction angle.

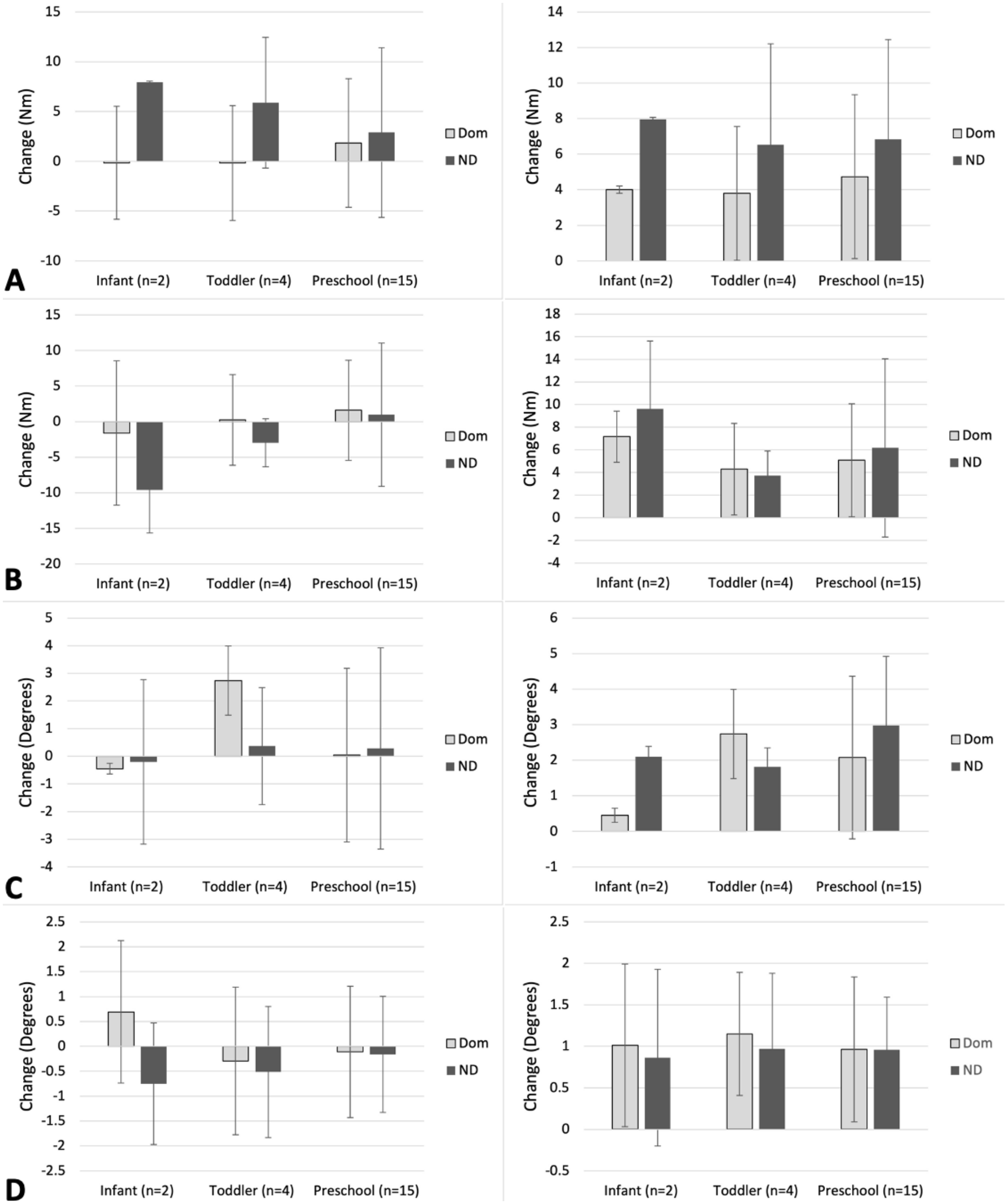

Figure 0.2: Mean and standard deviations of change (change on the left and absolute change on the right) for the participants when separated into groups based on the age of the children they care for. A) Peak knee flexion moment, B) peak knee adduction moment, C) knee flexion angle at heel strike, D) peak knee adduction angle.

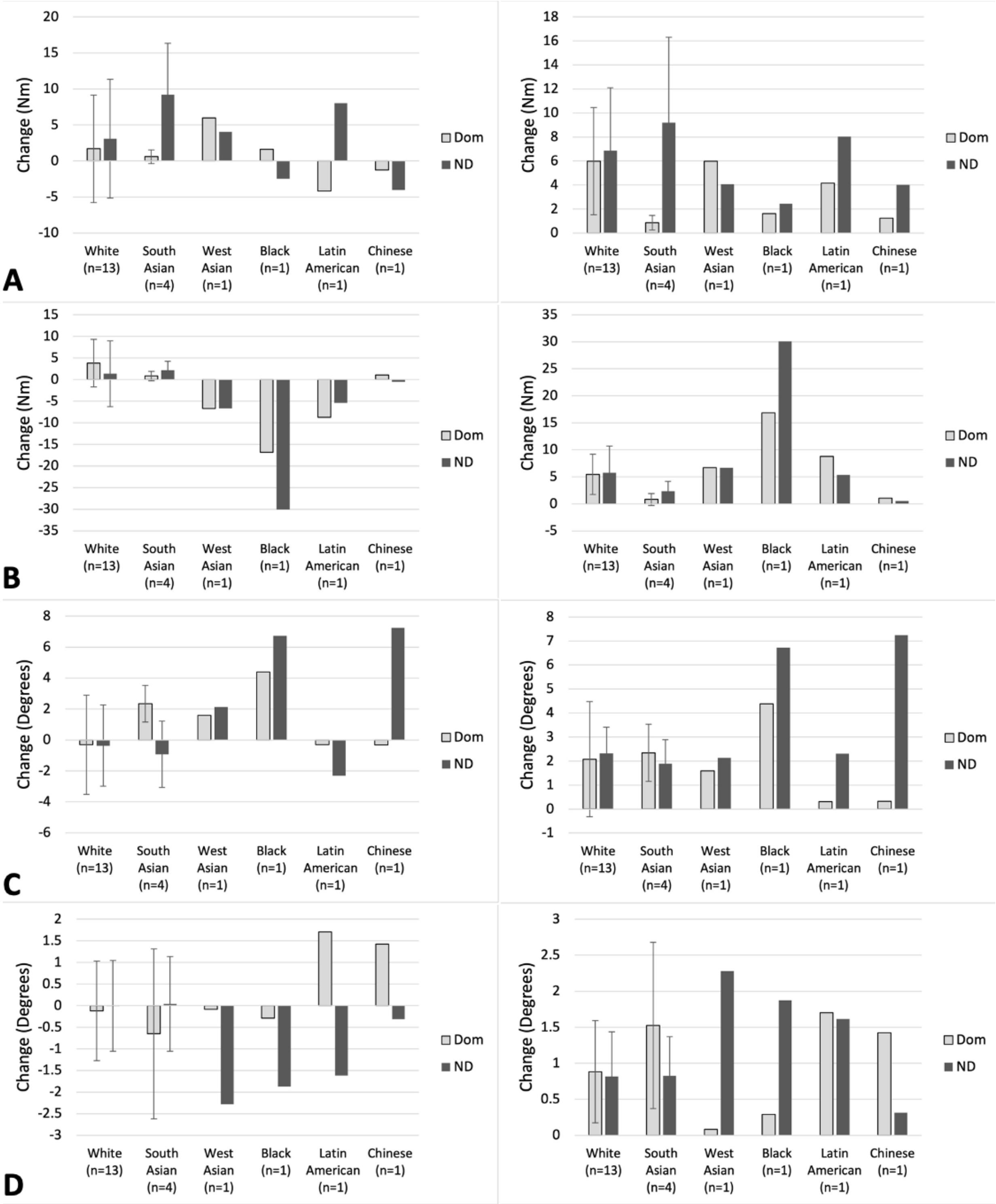

Figure 0.3: Mean and standard deviations of change (change on the left and absolute change on the right) for the participants when separated into groups based on their self-reported ethnicity. A) Peak knee flexion moment, B) peak knee adduction moment, C) knee flexion angle at heel strike, D) peak knee adduction angle.

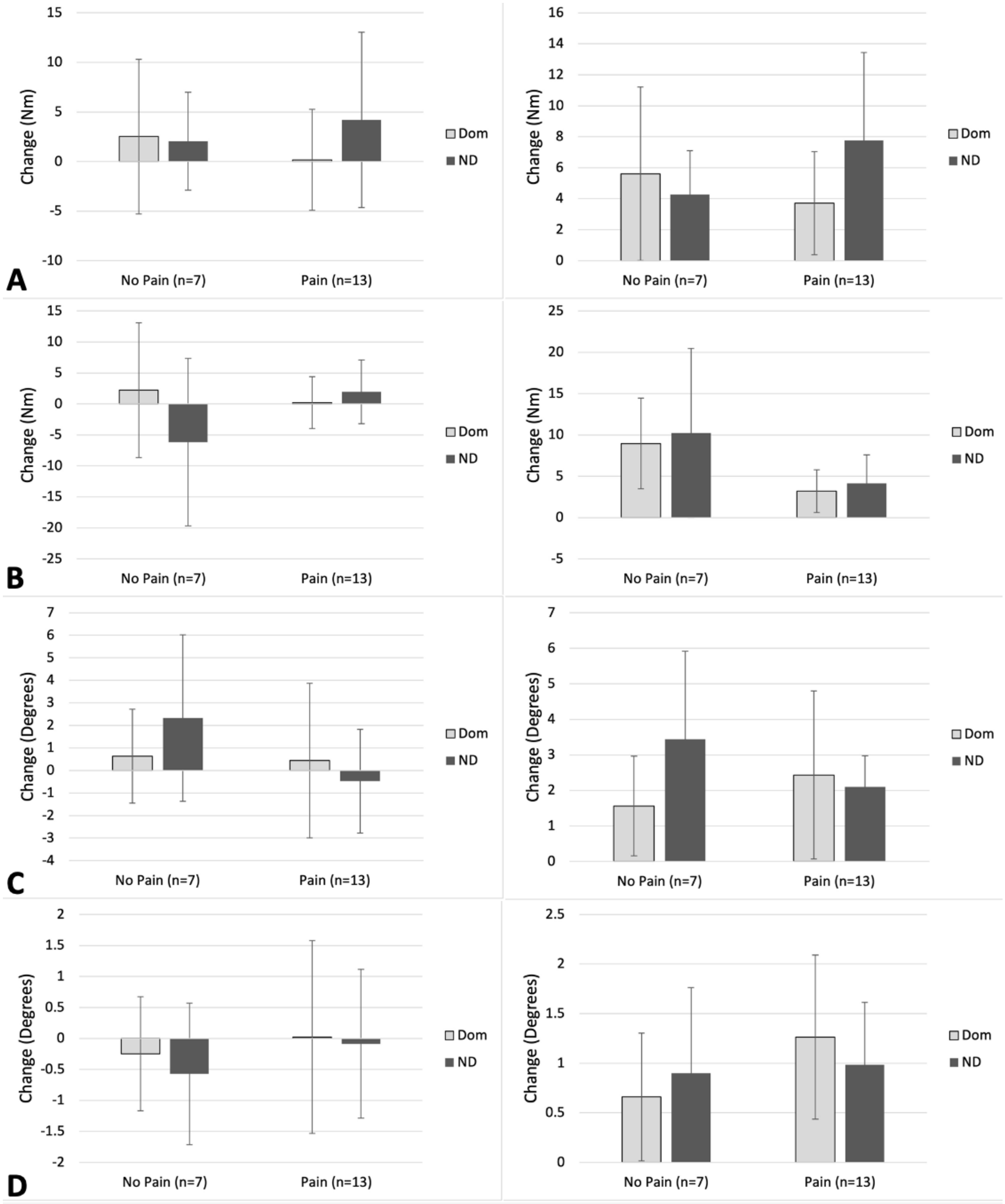

Figure 0.4: Mean and standard deviations of change (change on the left and absolute change on the right) for the participants when separated into groups based on whether or not they have foot pain. A) Peak knee flexion moment, B) peak knee adduction moment, C) knee flexion angle at heel strike, D) peak knee adduction angle.

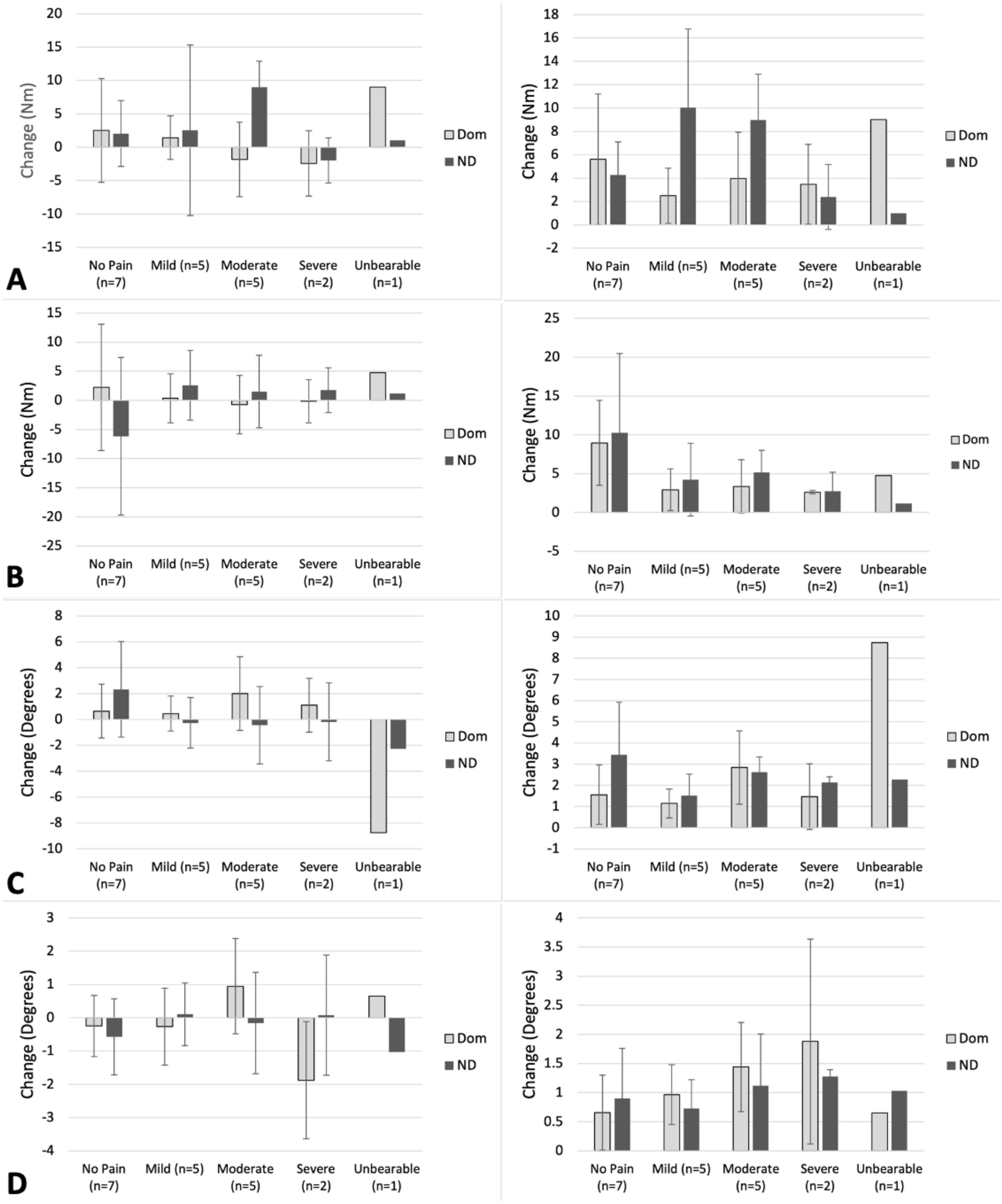

Figure 0.5: Mean and standard deviations of change (change on the left and absolute change on the right) for the participants when separated into groups based on the severity of foot pain. A) Peak knee flexion moment, B) peak knee adduction moment, C) knee flexion angle at heel strike, D) peak knee adduction angle.

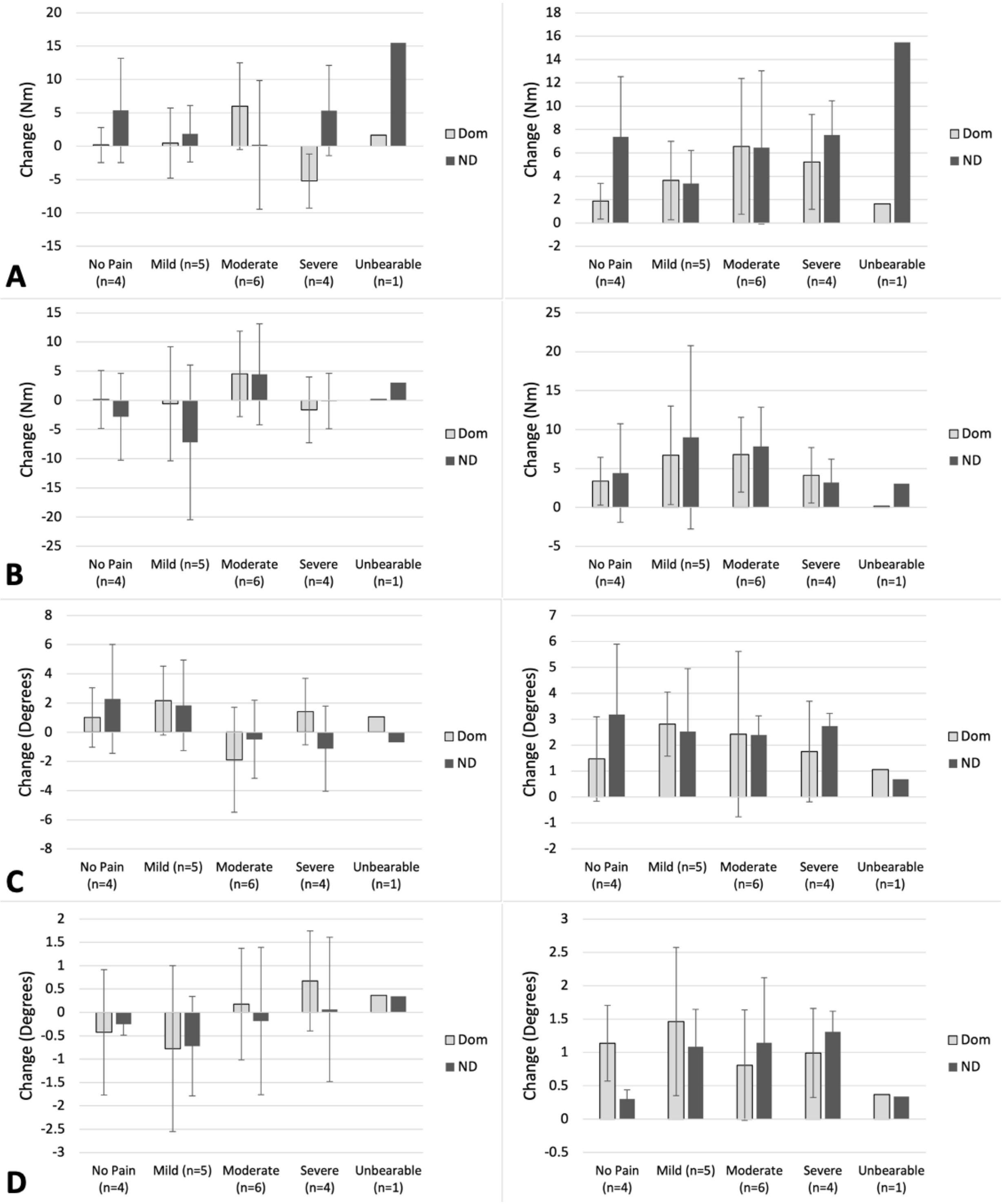

Figure 0.6: Mean and standard deviations of change (change on the left and absolute change on the right) for the participants when separated into groups based on the severity of their low back pain. A) Peak knee flexion moment, B) peak knee adduction moment, C) knee flexion angle at heel strike, D) peak knee adduction angle.

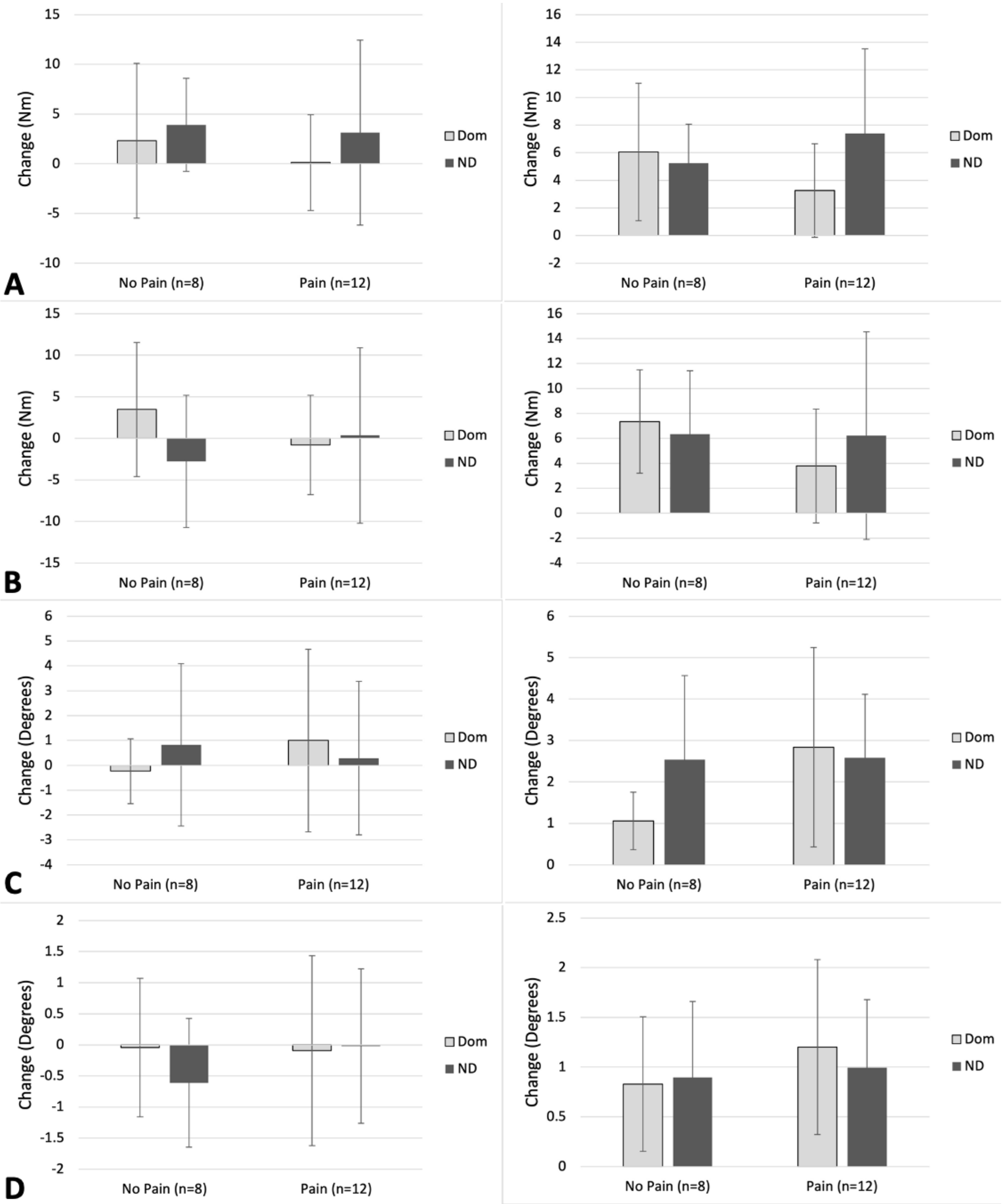

Figure 0.7: Mean and standard deviations of change (change on the left and absolute change on the right) for the participants when separated into groups based on whether or not they have knee pain. A) Peak knee flexion moment, B) peak knee adduction moment, C) knee flexion angle at heel strike, D) peak knee adduction angle.

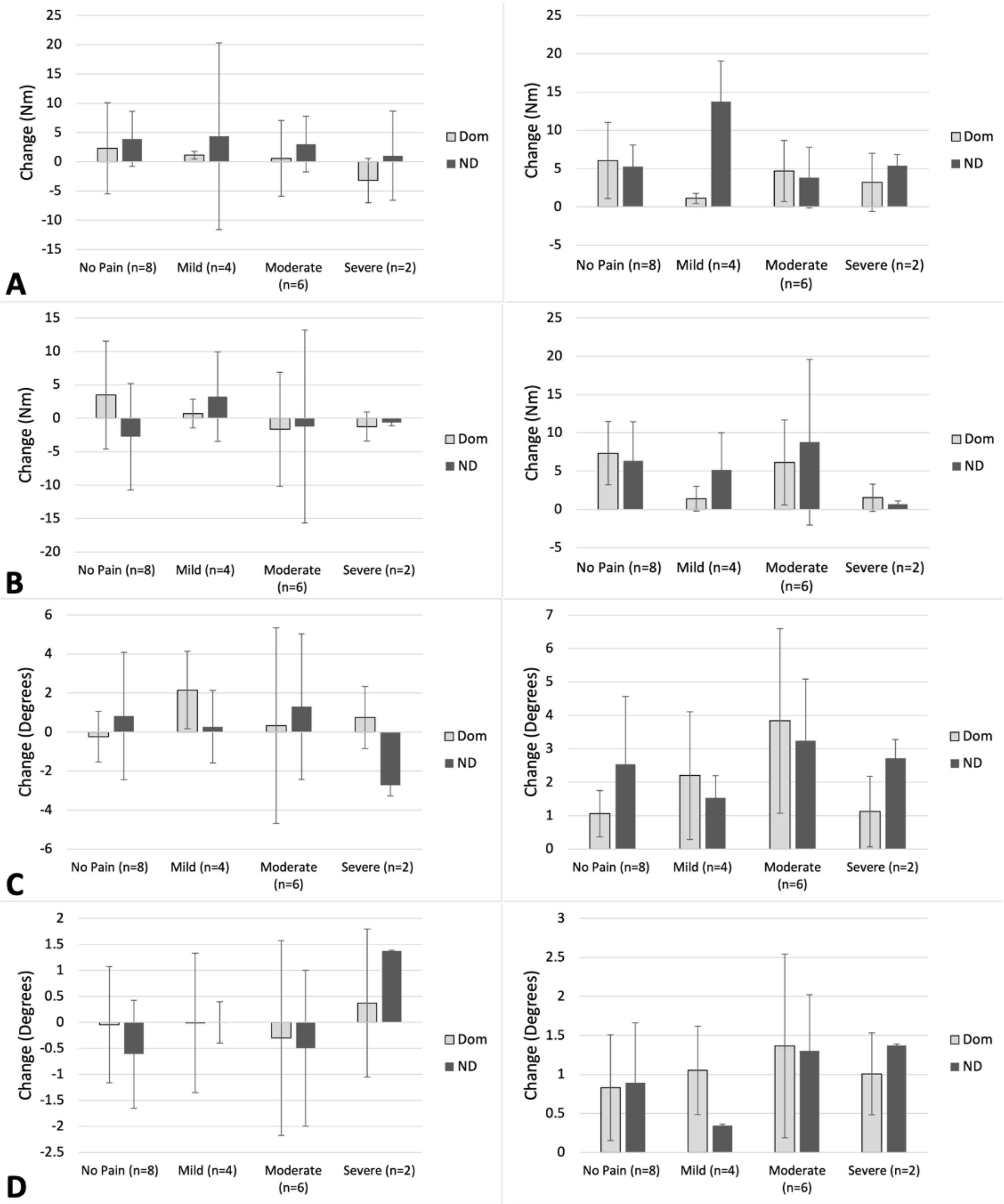

Figure 0.8: Mean and standard deviations of change (change on the left and absolute change on the right) for the participants when separated into groups based on the severity of their knee pain. A) Peak knee flexion moment, B) peak knee adduction moment, C) knee flexion angle at heel strike, D) peak knee adduction angle.

Appendix C: Questionnaire results

Table 0.1: Summary of self-reported musculoskeletal injuries/pain experiences within the last year (n=20).

Symptom	Region	Neck	Shoulder	Elbow	Hands and/or Wrist	Upper Back	Lower Back	Thighs	Knee	Feet and/or Ankles
Severity	**Mild pain**	6	4	2	7	3	6	3	5	6
	Moderate pain	5	5	1	2	5	6	2	6	6
	Severe pain	4	4	1	2	2	5	0	2	2
	Unbearable pain	3	1	0	1	1	1	0	0	1
Duration of symptoms	**< 1 week**	6	6	1	3	4	6	1	2	4
	< 1 month	2	2	1	2	3	2	0	3	1
	1-3 months	1	0	1	0	0	0	0	1	1
	3-6 months	0	0	1	1	1	0	0	1	0
	> 6 months	3	3	0	0	1	7	0	4	3
Occurrence rate	**Almost everyday**	3	4	0	2	2	7	0	5	3
	About once a week	6	4	1	4	2	1	0	0	1
	About one every two weeks	0	0	0	2	0	1	1	5	5
	About once a month	1	6	0	1	3	4	3	1	0
	About once a year	1	0	3	2	1	2	1	0	1

Table 0.2: Summary of self-reported musculoskeletal pain during specific occupational childcare work tasks (n=20).

WORK TASK	REGION WITH SYMPTOMS									
	Do not perform this task	**Neck**	**Shoulder**	**Elbow**	**Hand and/or Wrist**	**Upper Back**	**Lower Back**	**Thigh**	**Knee**	**Foot and/or Ankle**

Diaper changing	1	1	4	1	4	0	8	0	2	2
Feeding	7	0	1	0	1	0	0	0	1	2
Toileting	2	1	3	0	1	2	5	0	1	1
Grooming	2	0	2	0	1	0	2	0	1	2
Transferring	1	2	5	1	2	1	3	0	2	2

Table 0.3: Summary of self-reported beliefs on which interventions are needed to reduce musculoskeletal injuries in the occupational childcare (n=20).

	1 Not Needed	**2 Not as Needed**	**3 Neutral**	**4 Somewhat Needed**	**5 Very Needed**
Environmental modifications (Such as size and heights of tables, chairs, etc.)	1	1	8	4	6
Knowledge regarding the use of personal protective equipment (Timing for the use of lumbar supports, knee braces, etc.)	2	2	10	3	2
Postural education (Proper body mechanics, child handling techniques, etc.)	3	0	6	6	5
Work-time adjustment (Such as ways to arrange the work and break time)	3	3	8	3	3
Muscle strengthening (Frequency, intensity, and duration)	2	0	9	5	4

Appendix D: Within Participant Variability

Table 0.4: All participants' means and standard deviations of each outcome variable from six (three for dominant (Dom) and three for non-dominant (ND) leg) gait trials before and after their work shift

PID	Flexion Moment				Adduction Moment				Flexion Angle at HS				Adduction Angle			
	Pre		Post		Pre		Post		Pre		Post		Pre		Post	
	Dom	ND	Dom	ND	Dom	ND	Dom	ND	Dom	ND	Dom	ND	Dom	ND	Dom	ND
1	21.65 ± 3.25	12.64 ± 5.72	22.65 ± 1.72	18.90 ± 2.81	22.77 ± 3.46	32.94 ± 2.66	21.38 ± 4.66	29.13 ± 3.24	7.3 ± 0.6	3.2 ± 0.4	11.0 ± 0.5	5.4 ± 0.6	3.9 ± 0.2	4.7 ± 1.2	5.6 ± 1.3	4.4 ± 0.9
2	17.01 ± 1.40	17.60 ± 4.06	23.01 ± 4.38	21.67 ± 9.66	35.85 ±6.72	26.60 ± 0.58	29.13 ± 5.07	19.95 ± 3.20	7.8 ± 1.7	3.2 ± 1.0	9.4 ± 1.1	5.3 ± 1.4	1.9 ± 0.9	3.4 ± 2.5	1.8 ± 0.5	1.1 ± 0.8
3	19.16 ± 6.16	23.27 ± 6.76	36.11 ± 20.11	31.61 ± 19.08	32.84 ± 2.00	30.02 ± 1.12	47.97 ± 22.90	44.28 ± 19.14	9.7 ± 0.9	7.3 ± 0.5	9.3 ± 1.1	9.5 ± 0.7	9.2 ± 1.0	9.7 ± 0.2	9.2 ± 1.7	9.0 ± 1.3
4	18.82 ± 5.74	11.45 ± 3.64	25.42 ± 6.29	17.93 ± 3.29	39.73 ±2.10	39.83 ± 0.34	43.83 ± 1.52	36.12 ± 1.28	3.8 ± 1.3	7.5 ± 1.2	2.2 ± 1.7	6.8 ± 1.8	7.5 ± 0.9	5.5 ± 0.5	6.9 ± 2.7	4.4 ± 0.7
5	6.98 ± 2.11	10.43 ± 8.45	7.22 ± 4.21	24.91 ± 5.46	37.02 ±1.40	25.68 ± 1.64	37.39 ± 1.92	27.16 ± 0.26	4.2 ± 2.1	9.8 ± 4.0	8.1 ± 1.4	8.0 ± 1.9	3.2 ± 0.4	4.0 ± 1.3	2.0 ± 0.3	3.7 ± 0.7
6	33.24 ± 16.16	39.72 ± 13.26	37.10 ± 8.32	47.59 ± 16.94	44.93 ± 1.46	55.75 ± 4.10	50.51 ± 1.63	41.88 ± 4.48	9.4 ± 1.3	12.7 ± 0.7	8.8 ± 0.6	14.6 ± 2.4	4.5 ± 0.3	5.5 ± 0.9	4.2 ± 1.8	5.6 ± 2.0
7	42.51 ± 3.65	26.68 ± 10.06	32.20 ± 4.38	38.01 ± 6.70	44.21 ± 5.06	41.43 ± 0.77	48.87 ± 3.91	47.61 ± 1.29	0.1 ± 2.0	2.3 ± 1.7	4.5 ± 1.9	5.5 ± 3.4	4.0 ± 0.8	6.7 ± 0.5	4.3 ± 0.5	5.8 ± 0.5
8	28.85 ± 5.74	36.27 ± 0.85	32.94 ± 3.34	41.00 ± 5.91	32.91 ± 6.60	28.43 ± 2.10	34.48 ± 1.73	37.51 ± 0.35	8.3 ± 1.9	11.1 ± 1.4	6.5 ± 1.0	7.6 ± 0.2	7.6 ± 0.7	7.7 ± 0.2	9.9 ± 1.0	10.1 ± 0.3
9	9.95 ± 2.25	9.62 ± 1.32	16.72 ± 4.43	23.41 ± 4.47	22.83 ± 0.35	18.05 ± 1.35	26.32 ± 1.68	19.44 ± 1.92	7.4 ± 1.2	11.9 ± 2.0	7.9 ± 0.4	7.1 ± 0.6	4.6 ± 1.7	7.0 ± 0.4	4.6 ± 1.2	6.1 ± 0.4
10	7.56 ± 7.13	3.81 ± 3.14	7.03 ± 3.89	10.23 ± 5.18	40.62 ± 0.44	43.03 ± 1.76	40.90 ± 2.07	42.69 ± 0.85	5.9 ± 2.6	9.1 ± 0.6	7.8 ± 4.0	6.0 ± 1.9	3.9 ± 0.3	6.2 ± 1.6	5.3 ± 0.5	7.6 ± 1.5
11	3.43 ± 1.44	3.11 ± 0.99	1.77 ± 3.55	4.93 ± 0.79	28.48 ± 1.34	31.10 ± 1.02	37.24 ± 0.61	27.69 ± 0.88	11.7 ± 0.9	10.3 ± 0.5	9.9 ± 8.0	7.4 ± 0.3	1.0 ± 0.7	2.1 ± 0.9	0.0 ± 2.6	2.2 ± 0.6
12	16.11 ± 7.18	13.46 ± 6.82	17.75 ± 1.66	28.94 ± 4.74	27.73 ± 1.18	19.08 ± 1.00	27.88 ± 1.38	22.10 ± 0.35	6.7 ± 0.5	8.2 ± 2.4	7.7 ± 1.7	7.5 ± 0.5	6.3 ± 1.1	7.6 ± 0.7	6.6 ± 1.3	7.9 ± 0.6
13	19.55 ± 14.50	10.74 ± 3.18	17.44 ± 5.60	13.83 ± 6.07	21.60 ± 2.31	17.82 ± 0.95	15.15 ± 1.38	19.57 ± 2.29	10.5 ± 2.8	9.0 ± 2.1	11.6 ± 1.7	10.8 ± 1.5	13.1 ± 0.6	13.1 ± 0.2	11.6 ± 0.7	12.6 ± 0.3
14	10.35 ± 6.69	8.13 ± 4.30	4.46 ± 2.51	3.78 ± 2.99	20.80 ± 1.97	19.05 ± 0.40	18.03 ± 2.31	18.07 ± 0.23	15.2 ± 0.4	16.5 ± 1.1	14.8 ± 1.5	14.2 ± 2.1	9.3 ± 1.4	9.6 ± 1.0	8.6 ± 0.7	11.0 ± 0.8
15	38.52 ± 8.63	33.34 ± 10.67	47.52 ± 14.50	34.35 ± 11.56	56.07 ± 5.37	59.79 ± 3.40	60.84 ± 4.97	60.95 ± 5.98	9.0 ± 0.9	10.0 ± 1.3	0.2 ± 0.7	7.7 ± 0.3	8.0 ± 0.3	6.7 ± 0.7	8.6 ± 0.6	5.7 ± 1.1
16	43.62 ± 3.87	47.06 ± 9.26	45.24 ± 9.04	44.60 ± 8.92	40.58 ± 21.53	60.19 ± 27.92	23.73 ± 19.51	30.14 ± 3.51	8.8 ± 0.5	3.8 ± 3.2	13.1 ± 2.6	10.6 ± 5.6	10.8 ± 0.8	10.4 ± 4.1	10.5 ± 0.3	8.6 ± 0.6

17	19.43 ± 10.73	17.79 ± 1.60	11.49 ± 1.13	16.46 ± 1.46	8.12 ± 7.95	18.95 ± 0.65	16.79 ± 1.13	16.03 ± 0.90	8.6 ± 2.2	5.2 ± 0.6	10.4 ± 2.0	4.1 ± 1.1	11.7 ± 0.9	5.6 ± 1.0	10.1 ± 1.1	6.5 ± 1.3
18	39.48 ± 3.91	28.74 ± 6.45	35.32 ± 0.76	36.77 ± 5.24	44.95 ± 1.99	50.86 ± 4.86	36.18 ± 3.31	45.50 ± 13.90	-2.8 ± 1.8	-1.7 ± 0.8	-3.1 ± 1.8	-4.1 ± 1.7	4.4 ± 0.9	6.4 ± 1.9	6.1 ± 0.7	4.7 ± 0.5
19	20.11 ± 0.05	20.02 ± 5.20	21.15 ± 4.94	20.43 ± 5.98	27.91 ± 0.93	27.08 ± 3.56	30.37 ± 3.94	31.56 ± 0.93	4.5 ± 0.2	6.0 ± 2.2	7.1 ± 2.2	7.9 ± 2.2	5.4 ± 2.1	2.7 ± 1.7	2.2 ± 2.1	1.5 ± 1.4
20	24.84 ± 4.68	27.46 ± 11.74	26.43 ± 4.11	8.69 ± 4.63	28.46 ± 12.98	26.96 ± 12.97	32.13 ± 9.94	39.26 ±1.22	11.5 ± 1.8	8.6 ± 1.8	11.4 ± 2.5	10.0 ± 1.3	5.8 ± 0.2	6.0 ± 2.3	4.9 ± 0.6	6.3 ± 0.7
21	14.79 ± 0.78	10.85 ± 1.02	13.55 ± 2.59	6.84 ± 2.04	26.42 ± 1.54	22.82 ± 0.94	27.46 ± 1.10	22.30 ± 1.18	6.8 ± 2.4	9.2 ± 1.7	6.4 ± 0.5	16.4 ± 2.0	3.9 ± 0.5	6.3 ± 2.8	5.3 ± 1.0	6.0 ± 0.8