Evaluation of Functional Activity Compensation Strategies, Level of Physical Activity, Quality of Life and Management of Physiotherapy for Non-Operative Children with Legg-Calve-Perthes Disease

Author:
Abdulrhman Salah Mashabi

Supervisors:
Dr Tina Gambling, Dr Mohammad Al-Amri and Prof Molly Courtenay

A thesis submitted for the degree of Doctor of Philosophy
Year of Presentation: 2021

School of Healthcare Sciences, Cardiff University
Cardiff, Wales, UK

Abstract

Background

Legg-Calve-Perthes (Perthes) disease is defined as poor blood circulation in the hip joint and is associated with pain, limited range of motion, muscle weakness and joint instability. Physiotherapy is a key management approach to improve hip mobility and muscle strength to enhance daily functional activities. Walking was the only task that has been considered in the Perthes literature, while limited information is available regarding how children with Perthes could perform daily functional activities such as balance and squat activities. These activities have been recommended in the physiotherapy programme for non-operative children with Perthes to enhance their independence. Therefore, there is a need to investigate how non-operative children with Perthes perform during these activities to identify the abnormal movement pattern to help in setting an optimal rehabilitation goal. In addition, there is a need to understand the difficulties that may face patients with Perthes in the course of their lives. It is recommended that investigating physical activity level, quality of life, and how they manage the physiotherapy treatment is essential to understand Perthes disease's effect on children with Perthes and their families. Therefore, this thesis aims to provide essential knowledge to understand the effects of the disease better through:

- evaluating how non-operative children with Perthes compensate in their movement during three functional activities (walking, single leg balance and squat),

- evaluating physical activity levels and quality of life, and evaluating how they manage physiotherapy treatment.

Methods

This thesis was divided into two studies: study one aims to systematically review Perthes gait literature's quality and identify movement-compensation strategies during walking in non-operative children with Perthes. The quality of Perthes gait literature has been investigated by two independent reviewers using the adapted Downs and Black checklist. Study two aims to evaluate how non-operative children with Perthes perform during three functional activities (walking, single-leg balance and squat) by using the movement analysis toolkit, to evaluate the physical activity level and quality of life, and to evaluate how non-operative children with Perthes and their families manage the physiotherapy treatment by completing the questionnaires. Before investigating the abnormal movement pattern during three functional activities for children with Perthes, it is important to establish the reliability of the researcher on placing markers and the reliability of children walking to identify the source of error associated with biomechanical data. This reliability study has been investigated as part of the methods for study 2.

Results

The systematic review study identified eight articles that met all the inclusion criteria. The analysis of the overall agreement between two independent raters performing the adapted Downs and Black checklist on literature revealed an ‘almost perfect’ agreement as presented a Kappa value of 0.906 (95% CI: 0.84–1). The quality of Perthes gait literature displayed variations in data quality, with scores ranging from 12 to 17 out of 20 due to limitations on reporting, internal validity, external validity, and power information. The second study showed a statistically significant difference in the Perthes group compared to control in three functional activities ($P<0.05$). The hip joint was the most affected joint during functional activities as it showed lower minimum hip flexion and decreased hip rotation by approximately 7° on the affected Perthes leg compared to the control group. The kinetic data demonstrated that the peak of hip abductor moment was significantly higher in the Perthes group than the control group in three functional activities. In addition, children with Perthes demonstrated no statically significant difference in the level of physical activity compared to the control group (p>0.05), while they showed a statically significant difference (p<0.05) in quality of life as presented four scores lower than the control group. A questionnaire on managing physiotherapy treatment revealed that both non-operative children with Perthes and their parents reported greatly concerning pain.

Conclusion

The finding of movement-compensation strategy during functional activities and poor quality of life among non-operative children with Perthes may be due to pain, hip abductor muscle weakness, abnormal femoral head shape and lack of participation in the activities. Therefore, more research is needed to investigate the role of physiotherapy, pain management, and finding safe and enjoyable activities such as swimming and cycling to reduce the consequences of Perthes disease and help clinical providers set an optimal rehabilitation goal.

Dedication

This thesis is dedicated to the memory of Dr Tina Gambling.

She had so much knowledge, with a wonderful character. She left a great impact on people around her. Her continuous support and enriching guidance are what pushed me to go forward. There is no denying that I learned a lot from her.

Her death came as a sad, and shocking news. I was fortunate enough to be her student. My sincere gratitude to Dr Tina Gambling, and my deep condolences to her family and everyone who knew her.

Acknowledgements

First, I would like to express my full gratitude to Allah, who guided me in the completion of this work.

It would have been impossible to complete this thesis without the support and assistance of several people to whom I will always be grateful. Primarily, I would like to express my deep appreciation to my supervisors: Dr Mohammad Al Amri and Prof Molly Courtenay. Thank you for supporting me through the process and enabling me to learn skills and knowledge I had not considered possible. This thesis is a testament to your patience and belief in me, and I cannot thank you enough for your time and support over the years.

I would like to express my gratitude to Penelope Farthing and Catherine Purcell for their assistance in laboratory bookings. Special thanks also go to all study participants and their parents for their time and cooperation in this project; without them, this study would not have seen the light of the day. In addition, my thanks go to my wonderful colleagues for their support and their discussions, which have been of great value throughout this research.

Finally, I would also like to thank my family members – my mother, father, wife, sisters, brothers and daughters – for their continuing support and encouragement. Thank you for believing in what I was doing and always being there to cheer me up on this long journey.

Table of Contents

List of Tables

List of Figures

Chapter One: Introduction

1.1 Background

Legg-Calve-Perthes (Perthes) disease is defined as poor blood circulation in the hip joint due to idiopathic osteonecrosis. Patients with Perthes disease suffer mainly from the pain associated with functional activities such as walking (Krauspe et al. 1997; Nelitz et al. 2009). Patients with Perthes demonstrate restricted movement in their hip joints, mainly in the directions of internal rotation and abduction (Karimi and McGarry 2012; Svehlik et al. 2012). In addition, observational gait analysis reveals a limping pattern due to adductor muscle contracture or collapse in the epiphysis bone (Nelitz et al. 2009). Clinical factors that may worsen outcomes include a later age of onset, obesity, severe restriction of hip joint movement and female gender (Nelitz et al. 2009). The long-term outcomes of these problems, including instability and reduced hip range of motion (ROM), may lead to increased incidence of osteoarthritis or subluxation of the hip joint (Karimi and McGarry 2012). There are two options for the management of the above problems: operative and conservative methods. Physiotherapy plays an important role in both approaches. In pre- and post-operative management, patients with Perthes require physiotherapy to enhance hip mobility and increase hip muscle strength (Leroux et al. 2018). However, the physiotherapy literature has limitations as the hip joint is not measured in the dynamic position, which is essential when evaluating functional activities. Studying full biomechanical data, especially of the hip joint in static and dynamic positions while performing functional activities, could provide valuable knowledge to increase understanding of the nature of Perthes disease.

Children with Perthes display gait compensation and signs of poor postural control during walking activities, spending a relatively prolonged time standing on the non-affected side and reducing their gait speed (compared to control groups) (Westhoff et al. 2012; Stief et al. 2014). Gait compensation has been discussed in Perthes literature; however, the quality of these publications has not yet been evaluated and synthesised. This paucity of literature may lead to conflicts in recommendations between clinical providers. For example, Westhoff et al. (2006), Svehlik et al. (2012), and Westhoff et al. (2012) recommend performing ipsilateral trunk lean towards the involved side during walking to reduce pressure in the involved Perthes hip joint. However, Stief et al. (2014) oppose this recommendation because this movement has been found to adversely affect the knee joint and cause pain that could initiate degenerative changes in knee cartilage. These gait compensation studies did not measure hip muscle strength and evaluate the non-affected side (sound limb). Single-leg balance and squat activities are other areas that should be investigated in non-operative children with Perthes to understand how they may compensate in their movement. Single-leg balance is essential in most functional activities (e.g., walking, during the single-limb stance phase) and evaluates postural balance stability affected by traumatic musculoskeletal injuries (Gribble et al. 2004; Pau et al. 2015; Bonnechère et al. 2017). In addition, the squat is another important activity that challenges lower limb muscles throughout the extension chain (Eken et al. 2017). It is frequently performed while doing routine daily activities like sit-to-stand (Stevens et al. 2018). Therefore, these activities are important for daily functional activities that increase levels of independence (Bonnechère et al. 2017; Eken et al. 2017; Pirker and Katzenschlager 2017). Before collecting biomechanical data from children with Perthes, the quality of biomechanical data should be established in typically developing children by investigating the reliability of the researcher on placing markers and the reliability of walking between sessions to identify the sources of error associated with collecting movement data.

Reliance solely on biomechanical data is insufficient to understand the difficulties that may face patients with Perthes in the course of their lives. Neal et al. (2016) reported that obesity is commonly associated with Perthes disease; thus, physical activity levels and quality of life should be examined. In addition, Hailer et al. (2014) found that lack of mobility (including walking), pain and anxiety/depression are associated with Perthes disease, negatively affecting patients' general quality of life. Similarly, Leo et al. (2019) report pain, impact on sleep, and restrictions on playing and school attendance as possible causes of lower quality of life among children with Perthes. Helping children with Perthes and their parents' understand the management of physiotherapy treatment may increase their adherence to rehabilitation programmes. There is a lack of research considering the movement-compensation of non-operative children with Perthes during functional activities and linking this with physical activity levels and quality of life. Moreover, there is no study investigating how children with Perthes and their parents manage physiotherapy treatment. Therefore, evaluating how non-operative children with Perthes compensate in their movement during three functional activities and their levels of physical activity, quality of life and how they manage physiotherapy treatment may provide essential knowledge to build a good understanding of the effects of the disease.

1.2 Research questions

The research questions for this thesis are 1) What are the compensation strategies during three functional activities: (walking, single leg balance and squat)?; 2) what is the level of physical activity and quality of life among non-operative children with Perthes compared to typically developing children?; 3) how do children with Perthes and their families manage physiotherapy treatment?

1.3 Thesis aim

The overall aim of this thesis is to develop an improved understanding of the effect of Perthes disease on functional activities, physical activity level and quality of life and the management of physiotherapy treatment in non-operative children with Perthes. This understanding may provide early information to help clinical providers set optimal rehabilitation goals.

1.4 Objectives

1. To systematically review Perthes gait literature's quality and identify the movement-compensation strategies in non-operative children with Perthes during functional activities.
2. To evaluate how non-operative children with Perthes perform during walking, single-leg balance and squat.
3. To evaluate the physical activity level and quality of life between non-operative children with Perthes and typically developing children.
4. To evaluate how non-operative children with Perthes and their families manage the physiotherapy treatment.

1.5 Thesis structure

The thesis is structured in six chapters. The first chapter is an introduction to the thesis. The second chapter, the literature review, provides essential information about the nature of Perthes disease (including its definition, prevalence, diagnosis, prognosis, clinical features, and types of treatment) and identifies the gaps in knowledge regarding functional activities and the quality of related biomechanical data, level of physical activity, quality of life and how children with Perthes and their families manage physiotherapy treatment. Chapter three is a systematic review investigating the quality of Perthes gait literature, gait deviation among non-operative children with Perthes, and identifying knowledge gaps. Chapter four is the thesis methods. As part of the method, it is important to demonstrate the rigours of the data collection by establishing the reliability of the rater (researcher) on placing marker and the reliability of children walking to identify the source of error associated with movement data. Chapter five is a study designed to investigate the movement-compensation of non-operative children with Perthes during functional activities, their physical activity levels, quality of life, and how they manage physiotherapy treatment. The sixth chapter is the discussion which discusses the key findings of the three studies, the research implications, clinical implications, strengths and weaknesses and the conclusion for the whole thesis.

Chapter Two: Literature Review

2.1 Background

This chapter first provides essential information about the nature of Perthes disease, including its definition and prevalence. It then illustrates the causes, problems and clinical features of the disease. It is followed by presentations of the diagnosis, prognosis and management of the condition. The role of physiotherapy in the management of patients with Perthes is illustrated, followed by the importance of biomechanics and the biomechanics of the hip joint. Types of functional activities and their importance are then highlighted, followed by a section that explores the quality assurance of collecting biomechanical data. The final part of the literature review discusses the level of physical activity and quality of life of children with Perthes and how they and their families manage physiotherapy treatment. The relevant literature is critically appraised and considered as the basis for the current research project.

2.2 Search strategies

The literature search had two stages. The first stage of the process was to identify relevant articles concerning the primary pathologies associated with Perthes disease, including medical knowledge of Perthes disease, rehabilitation, functional activities, and quality of life. The second stage was to identify available literature regarding the quality of movement analysis data to identify the source of error associated with collecting movement data. For both stages, an online search of the medical literature was carried out utilising the electronic databases MEDLINE, Embase, Scopus and the Physiotherapy Evidence Database (PEDro) to collect relevant literature to form the basis for this project. The inclusion criteria for studies in this database search were: 1) full text, 2) published from date of inception to August 2020, and 3) English language. Systematic reviews, cross-sectional studies, experimental trials and longitudinal studies were included in the literature review (if relevant to the current study). The exclusion criteria were duplicated articles, articles dealing with other topics such as hip dysplasia, those without an accessible abstract (Table 1).

Table 1: Keywords included for literature search

	Stage one				Stage two
	Perthes Disease	Rehabilitation	Functional Activities	Quality of life	Quality of movement data
Keywords	(Perthes OR Hip necrotic OR Hip necrosis) AND (Child OR Kid OR Paediatric)	(Physiotherapy OR Physical therapy OR Rehabilitation) AND (Perthes OR Hip necrotic OR Hip necrosis)	(functional activity OR daily activity OR gait OR walk OR locomotion OR ambulation OR balance OR squat) AND (Perthes OR Hip necrotic OR Hip necrosis)	(Quality of life OR physical activity) AND (Perthes OR Hip necrotic OR Hip necrosis)	(Quality assurance and (gait analysis OR movement))
Results	2173	83	260	49	53
Excluded article (duplicated or irrelevant article)	2138	78	249	43	48
Relevant after reviewing	35	5	11	6	5

2.3 Perthes disease

Legg-Calve-Perthes disease is defined as a lack of blood circulation of the capital femoral epiphysis in children because of idiopathic osteonecrosis (Perry et al. 2012). It is often associated with a flattening of the femoral head, which often leads to subluxation of the hip joint (Stief et al. 2016). Perthes disease is considered a rare disease. Perry et al. (2012) report an incidence of Perthes disease in the UK of 5.7 per 100,000 children and note that it affects more boys than girls between the ages of 4 and 8 years. In addition, Kessler and Cannamela (2018) report the incidence of Perthes disease in the USA as 2.84 per 100,000 children, with the highest incidence in children aged 2 to 5 years and the lowest in children aged 9 to 12 years. Bilateralism has been reported as having an incidence of 10% to 12% and as rarely occurring simultaneously (Song 2011). There is no evidence that this disease is inherited (Song 2011).

2.4 Aetiology

The cause of Perthes disease is unclear (Nelitz et al. 2009; Leroux et al. 2018; Pavone et al. 2019). There are many potential causes of Perthes disease, such as repetitive micro-trauma, vascular insufficiency, skeletal retardation and genetic factor. First, it is assumed that repetitive micro-trauma of the femoral head produces minor fractures in the fragile bone tissue of the immature hip joint; findings among hyperactive children have been reported by Nelitz et al. (2009) and Leroux et al. (2018). The second assumption is that vascular insufficiency exists because of a lack of blood supply to the femoral head derived from the intra-articular vessels around the femoral neck. In addition, abnormalities of blood coagulation, blood viscosity and blood vessels may contribute to epiphyseal bone necrosis (Nelitz et al. 2009). Third, skeletal retardation has been observed in the urinary deoxypyridinoline/creatinine quotient. It has been shown in the condensation phase of Perthes disease and may indicate an abnormality of hypoactive skeletal metabolism (Nelitz et al. 2009). The last potential cause of Perthes disease is genetic factors. Miyamoto et al. (2007) reported that Perthes disease might be related to a gene that causes bone dysplasia syndromes. Howevere, Song (2011) stated that there is no evidence supporting the Perthes disease to be inherited. The previous possible potential causes of Perthes disease remain controversial, as reported by Leroux et al. (2018) and Pavone et al. (2019). Pavone et al. (2019) conducted a systemic review to analyse the available literature to investigate the aetiology of Legg-calve Perthes disease. They include 64 articles, and the result of this review was that the aetiology of Legg-calve Perthes disease is still debated. They attribute debating in the aetiology of Perthes disease to the lack of high-profile studies and limitation in terms of significant heterogeneity. Therefore, more studies are required to understand the causes of Perthes disease.

2.5 Diagnosis

Understanding the diagnosis of Perthes disease is crucial to deciding the most suitable intervention for each Perthes patient (Brech and Guarnieiro 2006). In addition, this knowledge will provide valuable information in enabling this PhD project to identify the severity and stage of each non-operative Perthes child participating in this project. The disease can be diagnosed by several different techniques, including X-ray, ultrasonography and magnetic resonance imaging (MRI). The standard method of diagnosing Perthes disease is to perform X-rays on two planes. Lateral X-rays of the pelvis and hip joint provide diagnostic information and classification and prognostic assessment of Perthes disease. Ultrasonography has also been utilised as a supplementary method to track the femoral head changes, especially synovitis or effusion (Nelitz et al. 2009). Nelitz et al. (2009) recommend using plain X-ray or MRI when a patient of typical age for Perthes complains of transient synovitis that persists for several weeks. In addition, MRI can positively predict the early stage of Perthes disease when an X-ray shows no change on plain film. However, MRI has not been suggested to have prognostic value, and it is therefore not utilised as a good standard diagnostic method (Nelitz et al. 2009).

Waldenström (1922) demonstrated four stages that all children with Perthes pass through during the course of disease based on radiological information; the initial, fragmentation, re-ossification and residual stages. In stage 1, the initial stage, the affected Perthes hip shows an asymmetric femoral epiphyseal size, which is smaller on the involved side. There is a greater density of the femoral head epiphysis with widening the joint space. The mean duration of this stage is six months (Herring et al. 2004). In stage 2, the fragmentation stage, some areas of the femoral head are fragments, with an area of separation between the medial and lateral portions of the femoral head. In addition, the acetabulum has an irregular shape. This stage ends when new bone develops in the subchondral areas of the femoral head. The mean duration of this stage is eight months (Herring et al. 2004). In stage 3, the re-ossification stage, the healing process begins, improving the shape of the femoral head and reducing its flattening. The re-ossification stage has a mean duration of 51 months and ends when the femoral head has re-ossified (Herring et al. 2004). The change in stage 4, the residual stage, depends on the severity of deformity of the femoral head, which may have a normal shape or present flattening or widening. In addition, the acetabulum and greater trochanter may change in shape during this stage (Herring et al. 2004). Catterall (1971) listed four classifications of the disease based on its effects on the femoral head. This classification has limited reliability and prognostic value (Nelitz et al. 2009) (Table 2).

Table 2: Catterall classification for Perthes disease

I.	Histological and clinical diagnosis without radiographic findings
II.	Sclerosis with or without cystic changes with preservation of the contour and surface of the femoral head
III.	Loss of structural integrity of the femoral head
IV.	Additional loss of structural integrity of the acetabulum

Salter and Thompson (1984) proposed a classification including only two groups, describing only the early stages of the disease by the extent of subchondral fracture shown in axial X-rays. The first group shows subchondral fracture damage to less than 50% of the femoral dome, corresponding to Catterall classification types I and II. The second group presents subchondral fracture to more than 50% of the femoral dome, corresponding to Catterall classification types III and IV.

However, this classification has a disadvantage because not all patients with Perthes are diagnosed in the early stages. The most widely adopted classification is that described by Herring et al. (1992). It depends on the height of the lateral pillar of the epiphysis of the femoral head, as shown on an anterior-posterior X-ray view in the early fragmentation stage (Figure 1). This “lateral pillar” classification is considered to have a high prognosis value and high inter-observer reliability compared to the Catterall classification (Ismail et al.1998). The predictive value of the Catterall classification is higher based on the patient’s age at the onset of the disease (Gigante et al. 2002). Therefore, the Catterall and Herring classifications have the greatest prognostic value and are presented in most Perthes literature.

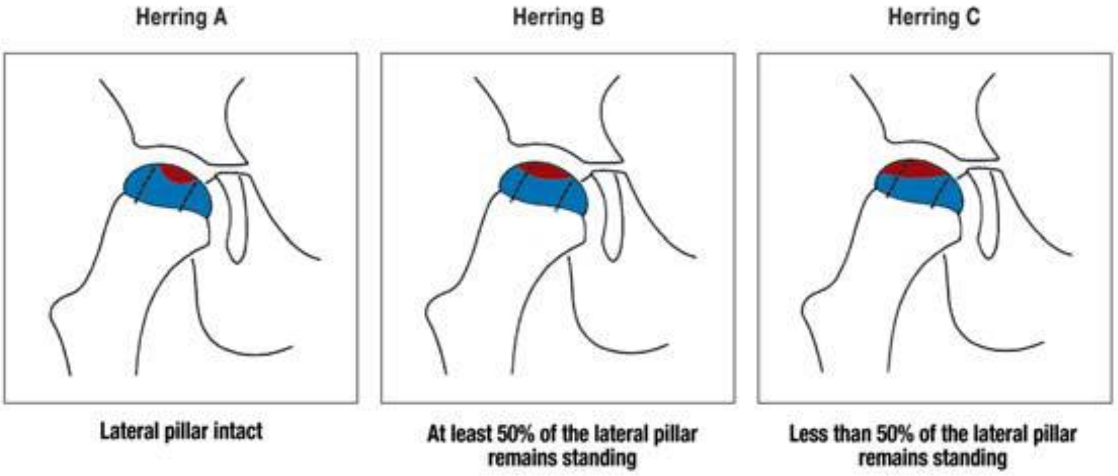


Figure 1: Herring’s “lateral pillar” classification, based on the height of the lateral pillar (necrotic area marked in red) (Nelitz et al. 2009)

2.6 Prognosis

More than 80% of affected hips have favourable outcomes that are maintained into the fourth decade of patients’ lives (Nelitz et al. 2009). young children (i.e. aged under six) at the beginning of disease onset will have a good prognosis because of the higher hip joint recovery rate at this age (Nelitz et al. 2009). Imperative prognostic components include late age at disease onset, limitation of ROM, radiologically visible negatively affected hip joint, and presence of any “head at risk signs”. Typical “head at risk signs” have been identified as lateralisation of the femoral head in the hip bone socket (subluxation), lateral epiphyseal calcification and metaphyseal cyst formation. Hip joints classified as Catterall types III and IV and Herring type C will have a poor prognosis (Hefti and Clarke 2007).

2.7 Clinical features

Most patients with Perthes disease suffer from pain, which may be associated with functional activities such as walking (Karimi and McGarry 2012). Pain mainly presents in the groin area and is often provoked during physical activities; in 25% of patients with Perthes, the pain radiates into the lower limbs, including the thigh and knee. It is thus recommended that when a child presents with knee pain, the hip joint should be carefully examined (Krauspe et al. 1997; Nelitz et al. 2009). In patients with Perthes disease, hip joint ROM is restricted mainly in internal rotation and abduction due to pain in the groin area as a result of alternation growth of femoral bone (Karimi and McGarry 2012; Svehlik et al. 2012). In addition, a functional examination during walking movement shows a limping pattern due to adductor muscle contracture or collapse in the epiphysis bone. Clinical factors that may worsen outcomes include a later age of onset, obesity, severe restriction of the hip joint movement and female gender (Nelitz et al. 2009). The long-term outcomes of these problems, including instability and reduced hip ROM, may lead to increased incidence of osteoarthritis or subluxation of the hip joint (Karimi and McGarry 2012).

2.8 Management

The management of Perthes disease is controversial because it depends on the surgeon's preference and experience and the psychosocial level of the patient and their family (Mazloumi et al. 2014). There are two options for managing Perthes disease, operative and conservative methods, based on the concept of containment. Containment involves maintaining the femoral head within the acetabulum throughout the entire evolution of the disease, thereby protecting the vulnerable segment of the epiphysis from being subjected to deforming forces (Muirhead-Allwood and Catterall 1982). The choice of management is related to the severity and onset of the disease (Mazloumi et al. 2014).

The operative management can be divided into four different operative approaches to achieve containment, which are:

1. Femoral varus osteotomy (FVO), an established operation for Perthes disease that aims to preserve the spherical shape of the femoral head (Kim et al. 2011).
2. Pelvic redirection osteotomy, an operation that aims to redirects the entire acetabulum following a complete trans-iliac osteotomy to enhance coverage of the femoral head (Salter 1984).
3. Lateral shelf acetabuloplasty (Ghanem et al. 2010).
4. Chiari osteotomy (Ghanem et al. 2010).

Lateral shelf acetabuloplasty and Chiari osteotomy are indicated for cases where pelvic redirection osteotomy is deemed insufficient – due to a lack of either concentricity or congruency or both – to produce enough acetabular displacement fragment to ensure optimal coverage of the extruded femoral head (Ghanem et al. 2010).

The many advantages of this operative management approach include correcting limb shortening (because it adds to the length of the limb), improving hip ROM, reducing joint subluxation and providing better radiographic sphericity of the femoral head (Laklouk and Hosny 2012; Saran et al. 2012; Rich and Schoenecker 2013). Its disadvantages are hospitalisation, immobilisation and a high level of pain (due to surgery). These disadvantages raise concerns for patients and their families and may affect the choice of management option (i.e. whether operative or non-operative management is chosen) (Mazloumi et al. 2014).

The second management option to achieve containment is a conservative approach that aims to improve hip ROM and decrease compression and pain level. Hip movement can be improved through physiotherapy, the BOTOX injections into the contracture or weakening of iliopsoas and adductor hip muscles if presented to restore muscle balance (Seyler et al. 2008; Nelitz et al. 2009). The role of intramuscular BOTOX injections in treating functional shortening of the iliopsoas and adductor hip muscle has been investigated by Westhoff et al. (2003). The procedure of BOTOX injections was performed in Westhoff et al. (2003) study 26 times in 13 patients (seven males, six females; mean age 11 years. Indications were functional iliopsoas shortening due to cerebral palsy (17 hips), hereditary spastic paraplegia (four hips), and Perthes disease (five hips). The result showed no complications were encountered for using BOTOX injection. Therefore, Westhoff et al. (2003) recommended BOTOX injection for children with Perthes in the iliopsoas and adductor hip muscle to prevent a fixed deformity and reduce hip pain associated with the walking activity. Thomas splint, abduction splints, Petrie casts, crutches, and bed rest (with or without traction) are other conservative approaches to decrease hip joint compression and improve containment (Nelitz et al. 2009). The conservative management approach has advantages, including improved hip ROM and reduced compression and pain level, and children and families prefer this management option (Brech and Guarnieiro 2006; Logan et al. 2019). The disadvantage of this approach is that the shape of the femoral head does not change radiographically (Brech and Guarnieiro 2006).

2.8.1 Comparison of operative and conservative management on treating Perthes disease

Two systematic reviews by McGarry (2012) and Galloway et al. (2020) have been identified, investigating the role of operative and conservative management in treating Perthes disease. First, Karimi and McGarry (2012) conducted a review comparing the effectiveness of surgical and conservative approaches to Perthes disease management. This review aimed to determine appropriate pathways for the management and the evidence of success to clinical outcome. The success of surgical and conservative approaches was based on the age of the disease onset, follow-up period, and the outcome. They included 50 articles and divided them into four themes that depend on the management method: containment, non-containment; surgery; non-treatment. The results of this review highlight that it is difficult to conclude whether one approach or the other is more effective. They found some evidence that supports the non-treatment approach (leaving the patient without treatment) to be as effective as conservative or surgical management. They recommended more research to determine the effectiveness of conservative and surgical treatment. However, this review did not include the physiotherapy approach as a conservative management method. The second systematic review is Galloway et al. (2020), who investigate the role of non-surgical management of Perthes disease. The non-surgical management includes physiotherapy with/without surgical intervention, orthotic management, and no treatment. It included 15 studies: eight prospective cohort studies and seven retrospective cohort studies. Galloway et al. (2020) found that the non-surgical management primarily focused on orthotic management (14 out 15 studies) and less focused on physiotherapy management (5 out 15 studies). This systematic review revealed a difference in non-surgical management outcome associated with the child's age at the time of diagnosis and intervention.

The previous two systematic reviews showed a lack of evidence regarding the effectiveness of management for Perthes disease; this may be due to a lack of high-quality randomised trials. In addition, there is limited information regarding physiotherapy management in the Karimi and McGarry (2012) study. In operative management, hip ROM should be regained before surgery to achieve better containment of the hip joint, as suggested by Mazloumi et al. (2014). In addition, children with Perthes need physiotherapy post-surgery to enhance hip joint mobility and increase hip muscle flexibility and strength (Brech and Guarnieiro 2006). Therefore, the following section discusses the role of physiotherapy as a conservative method in managing Perthes disease as it is has been suggested as an essential management approach in both operative and conservative approaches (Leroux et al. 2018).

2.8.2 Role of physiotherapy management

As discussed in section 2.7, pain is an early manifestation of Perthes disease, which may be situated in the hip; it is ordinarily reported in the medial side of the thigh or knee and can affect daily life activities (Nelitz et al. 2009). During clinical examination, patients with Perthes may show a reduction in hip movement, especially in abduction, flexion and medial rotation, which may prompt atrophy of the thigh muscles caused by lack of utilisation of the limb (Nelitz et al. 2009). They may also show decreased abductor hip muscle strength because of expanded growth of the greater trochanter and contracture in the flexion and abduction muscles of the hip joint (Nelitz et al. 2009). The greater trochanter's expansion is related to a separate extracapsular blood supply in the hip joint that allowed the unaffected greater trochanter to grow and expand relative to the affected femoral head and neck (Akpinar et al. 2019). This relative expands the growth of the greater trochanter leads to weakening the hip's abductor muscles (Akpinar et al. 2019). Thus, it is necessary to measure hip movement because limited hip movement has been reported as one of the first signs of hip subluxation (Brech and Guarnieiro 2006; Nelitz et al. 2009). Measuring the muscle strength around the hip joint is also essential because treatment outcomes are directly related to hip ROM and muscle strength, as Brech and Guarnieiro (2006) and Nelitz et al. (2009) suggested. Therefore, the role of physiotherapy is to help children with Perthes disease manage their condition by focusing on strengthening muscle and improving hip ROM using the right approaches to ensure no further complications such as early hip degeneration (Brech and Guarnieiro 2006). It is reported that excellent results will have been achieved when patients with Perthes have full hip ROM with no symptoms of pain or dysfunction (Brech and Guarnieiro 2006; Nelitz et al. 2009).

Four studies have been found investigating the role of physiotherapy in managing Perthes disease. Two of these found favourable results from physiotherapy management for patients with Perthes, while two did not support the role of physiotherapy as a management approach for patients with Perthes. The following studies discuss and highlight the primary outcomes to understand the physiotherapist role in enhancing Perthes' hip movement.

Brech and Guarnieiro's (2006) study demonstrates the role of physiotherapy in enhancing hip movement and muscle strength among patients with Perthes. This research compared ROM and muscle strength around the affected hip joints of Patients with Perthes who received 12 weeks of physical therapy to patients in a control group who did not receive physiotherapy treatment. The severity of the disease in patients was identified by Catterall radiographic classification. The physiotherapy programme included passive muscle stretching exercises of the involved hip (aiming to improve hip movement) and straight-leg-raise exercises to increase hip muscle strength. The hip movement was assessed using a manual goniometer tool, and muscle strength was measured on a scale of 0 to 5 points using a manual muscle test. It was found that the group that received physical therapy demonstrated significant improvement in hip joint movement and hip muscle strength, while those in the control group showed a significant reduction in hip joint movement and no change in muscle strength. However, the radiographic data did not reflect the hip ROM and muscle strength improvements, which remained the same. They recommended further followed-up for future analysis to examine the radiographic condition of the hip joint.

In another case study, Logan et al. (2019) recruited a six-year-old boy with bilateral Perthes who had severe necrosis (lateral pillar/Herring stage C bilaterally). After 11 years of treatment – including hip adductor tenotomy, drugs, cast/bracing, stretching and pool therapy – the boy expressed excellent functional and radiological measurement with congruence between femoral head and acetabulum and was able to participate in competitive activities such as soccer without pain. Logan et al. (2019) recommended physiotherapy as an element of Perthes treatment alongside drugs and cast/bracing. However, Logan et al. (2019) do not provide sufficient information about the physiotherapy programme in their study, including only a home stretching exercise for the hip. In addition, they did not provide information regarding hip muscle strength pre- and post-treatment. This information is crucial to identify any reduction in the effect of Trendelenburg’s sign, a common manifestation of Perthes disease (due to hip abductor muscle weakness) associated with walking (Westhoff et al. 2006; Westhoff. et al. 2016).

Despite the favourable results shown in the above two studies (e.g. children with Perthes displayed improvement in hip ROM and muscle strength), certain limitations should be considered. The Brech and Guarnieiro (2006) study used a prospective parallel-group controlled study design to investigate the physiotherapy exercises possible effect compared to observational follow-up in patients with Perthes disease. This prospective design might lead to selection bias as they divided patients with Perthes disease according to the patients’ availability, which means the baseline data between groups was variant. For example, group A (control group) included seven patients who were Catterall type II and two patients who were Catterall type III, while group B (intervention group) included two patients who were Catterall type I, four who were Catterall type II, and three who were Catterall III. Therefore, randomisation is essential to reduce the likelihood of selection bias and help researchers and reviewers gain good insight into research results (Kang and Lee 2019). Although Brech and Guarnieiro (2006) used valid and reliable measurement tools such as manual goniometer and manual muscle test (Cuthbert and Goodheart 2007; Nussbaumer et al. 2010), they did not assess dynamic ROM of the hip joint such as walking for patients with Perthes, providing information solely on static ROM measured by a manual goniometer laying on the bed. This measurement of static ROM does not investigate whether the physiotherapy approach improves hip movement because the static ROM omits essential factors such as ground reaction force (GRF) associated with functional dynamic activities. According to Newton's third law, the GRF is the force exerted by the ground on a body in contact with it. When a subject is in a standing position, the GRF corresponds with the subject's weight. When the subject is moving, the GRF increases due to acceleration forces (Meadows and Bowers 2019). In addition, Tsegaw (2014) emphasised investigating the forces around affected joints to guide proper clinical decision making. Tsegaw (2014) reported that clinical gait observations relying on the naked eye might miss the interplay of forces that lead to an injured joint, and researchers might miss the link between physical forces and clinical outcomes. Therefore, measuring dynamic hip movement (including force) in patients with Perthes is highly important for clinical provider to understand the mechanism of joint dysfunction during functional activities such as walking and set an optimal rehabilitation programme.

The other two studies that investigated the role of physiotherapy for patients with Perthes indicate no or negative effect of a physiotherapy approach on the Perthes hip joint (Wiig et al. 2008; Larson et al. 2012). Wiig et al. (2008) studied 368 patients with unilateral Perthes disease from 28 hospitals between 1996 and 2000. The patients' hips were classified radiologically according to a modified Catterall and Harries classification. A total of 358 patients with Perthes (97%) attended the five-year follow-up. The choice of one of three methods of management was based on a surgeon recommendation: physiotherapy (55 patients), Scottish Rite abduction orthosis (26 patients) or proximal femoral varus osteotomy (71 patients). Children with Perthes disease who had less than 50% hip necrosis (Catterall groups I or II) received physiotherapy that included ROM exercises and muscle-strengthening exercises. The results show that in children aged over six years at diagnosis with more than 50% of femoral head necrosis, proximal femoral varus osteotomy provided a significantly better outcome than orthosis or physiotherapy (p=0.001). There was no significant difference between the physiotherapy and orthosis groups (p=0.36), and no significant difference in outcome was found following different treatment methods in children with Perthes under six years of age (p=0.73).

The Larson et al. (2012) study showed a high prevalence of degenerative changes in the hips of patients with Perthes who were treated non-operatively at 20-year follow-up. The study involved 56 patients with Perthes between the ages of 16 and 24 as part of a multicentre prospective cohort trial. Patients with Perthes were treated using the following five methods, based on a surgeon's recommendation: hip ROM exercise, weight-bearing abduction bracing, no treatment, femoral osteotomy and innominate osteotomy. The patients returned for physical examination, radiographs and completion of outcome measures, including non-arthritic hip score (NAHS) and Iowa hip score (IHS). The study results reveal that a cohort of patients with Perthes evaluated 20 years after non-operative treatment commonly presented with hip pain and joint dysfunction. Four patients with Perthes had already undergone joint replacement or hip osteotomy surgery, and 76% of the 54 hips not requiring further surgery were at least occasionally painful. At least half of the patients had poor or fair outcomes, according to IHS and NAHS.

The studies of Wiig et al. (2008) and Larson et al. (2012) have certain strengths, including the multicentre setting, which may generalise results. Wiig et al. (2008) used two kinds of radiological classifications with diagnostic and prognostic value, and Larson et al. (2012) utilised two valid questionnaires (NAHS and HIS). However, the results of both papers should be considered with caution due to several limitations. The primary concern in Larson et al. (2012) is that this study may have selection bias because it included patients who had complications and may have attended follow-up sessions in order to seek treatment; patients who had fewer complications and could have reported better results may not have returned. Another weakness in both Wiig et al. (2008) and Larson et al. (2012) is that the frequency, duration and types of exercises applied in the physiotherapy programmes to improve hip movement in patients with Perthes are not clearly described. This information regarding physiotherapy programmes is essential to help physiotherapists design an effective treatment for children with Perthes disease. Another limitation in both studies is the reliance on radiological data alone; although this data is important, it is unknown whether pain symptoms, hip ROM and muscle strength were improved after the different management approaches employed in these studies. For example, Brech and Guarnieiro's (2006) study found no difference in radiological data after the physiotherapy treatment for children with Perthes disease, but the hip muscle and mobility were statistically improved. Therefore, it is important to measure the range of motion and the level of muscular strength of the hip along with radiographic data to determine the improvement of the hip condition; because the result of treatment is directly related to the hip ROM, a good outcome is when the patient has no symptoms of pain and total hip ROM (Jacobs et al. 2004; Brech and Guarnieiro 2006).

2.8.3 Summary of the role of physiotherapy

The studies discussed in this section used the prospective cohort design to describe physiotherapy role management for patients with Perthes. No highly evidence-based research, such as a randomised controlled trial, has been published to provide clear evidence about the effects of physiotherapy management for patients with Perthes. The outcomes of physiotherapy management show conflicting results. Most of the previous literature relies on radiographic data to determine whether a physiotherapy approach is effective or not. Brech and Guarnieiro's (2006) study found that radiographic data in a Perthes group who received the physiotherapy treatment were unchanged, whereas ROM and muscle strength were significantly improved. Therefore, even when the radiographic data does not change, it is essential to measure hip movement and muscle strength after treatment to have clear information on the role of physiotherapy in treating patients with Perthes. Both Brech and Guarnieiro (2006) and Wiig et al. (2008) suggest that physiotherapy management is applicable for patients with Perthes who have less than 50% hip necrosis (Catterall groups I, II or III) and may have a favourable outcome. However, little work discusses how this group of patients might be dynamically evaluated when performing daily functional activities. The dynamic evaluation of the hip joint considering the joint forces while performing functional activities such as walking could provide essential knowledge to clinical providers (physiotherapists and surgeons) to understand the mechanical loading in the hip joint. This information might help establish an optimal treatment plan to reduce hip loading and enhance functional ability among patients with Perthes by enhancing hip mobility and muscle strength. Therefore, the following section discusses the biomechanical approach importance in measuring dynamic activities such as walking.

2.9 Definition and importance of biomechanics

Human movement is accomplished through complex and highly integrated components, including bones, muscles, ligaments and joints within the musculoskeletal system. Any damage or lesion in any of the individual components of this system will interrupt their mechanical integration and cause abnormal movement (Lu and Chang 2012). However, good modification, manipulation and control of the mechanical environment can avoid injury, treat abnormality and accelerate healing and rehabilitation time (Lu and Chang 2012). Biomechanics is defined as the study of the forces that act on a body and the effects they produce. Bates (1991) suggests that biomechanics is an intersection of biology, physiology, anatomy, physics, mathematics and chemistry to solve complex problems in medicine and health. Hay (1973) describes biomechanics as the science that examines the forces acting upon and within a biological structure and the effects produced by such forces. Alt (1967) refers to biomechanics as the science that investigates the effects of internal and external forces on a human body at rest (static) and during movement (dynamic).

Biomechanical research in human development focuses on evaluating essential movement patterns across the human life span. Individuals of different ages are examined while performing a variety of functional daily living activities. The activities can then be quantified, described and analysed. Biomechanical analysis is specifically essential in quantifying the development of motor skills and movement patterns such as walking, kicking, jumping, throwing and catching. Research in this area has resulted in the characterisation of typical activity patterns for each age group. These patterns can be compared to an individual’s performance to determine his/her level of ability at any age. This type of analysis has been performed for various daily living activities across the human life span, including ascending and descending stairs, rising from and lowering onto a different level (such as a chair or bed), lifting and carrying objects, and pushing pulling objects. Again, the evaluation and quantification of each type of activity at various ages allow comparisons to be made between ages and makes it possible to evaluate an individual’s skill or ability in a specific activity at a particular age. Biomechanists have used high-speed camera systems and force platforms to capture and analyse slight movement changes in young children. The data from these devices have assisted biomechanists in objectively examining movements such as body sway during sitting and standing and ROM at the joints during walking. The results are then shared with paediatricians and paediatric physical therapists to design an effective treatment. In particular, such objective biomechanical measurements are used to evaluate therapies for children with developmental movement disorders (e.g. cerebral palsy and spina bifida).

Baker et al. (2016) conducted a review to highlight the importance of clinical gait analysis as the process of recording and interpreting biomechanical measurements of walking to support clinical decision-making in case of gait dysfunction among children with cerebral palsy. Cerebral palsy (CP) is the most common physical disability in childhood (Himmelmann et al. 2010). Children with CP present with varying motor deficits due to the upper motor neuron dysfunction, including neuromotor impairments and pathological movement patterns (Sussman 2010). The most common evaluation tool for the patient with CP is the clinical examination of the child, assessing joint mobility, tone, spasticity, muscle strength and degree of selective muscle control (Rathinam et al. 2014). However, there is a need for an accurate dynamic evaluation tool, which has the capacity to objectively quantify the child's motor functions with CP compared to typically developing children (Baker et al. 2016). Therefore, clinical gait analysis allows studying dynamic movement and supports the clinical treatment decision-making of patients with CP (Baker et al. 2016). There are a variety of goals using clinical gait analysis in CP, which are to assess the severity, extent and nature of the functional deficits to support the treatment decision making (Baker et al. 2016). In addition, the determination of the type of treatment is based on the integration of clinical examination and the clinical gait analysis data (Baker et al. 2016). Apart from the pre-treatment assessment, a follow-up analysis of the gait pattern after treatment enables monitoring of the progress and objective evaluation of the patient-specific outcomes (Baker et al. 2016). Gait analysis may provide the clinical provider with the necessary information to individualise the therapy programme (Desloovere et al. 2006; Franki et al. 2014). For example, De Mattos et al. (2014) used the gait analysis method to compare hamstring transfer and hamstring lengthening procedures in ambulatory children with cerebral palsy to decrease knee flexion during the stance phase. The result revealed that both groups improved maximum knee extension in the stance phase at the initial follow-up and maintained this at the long-term follow-up. Only the hamstring transfer group showed statistically significant ($p<0.05$) improvement in the peak hip extension power in the stance phase at the first post-op study, and this increased further at the final follow-up. The result of this study may help the clinical providers choose between two different techniques to treat flexed knee gait in patients with CP by showing the long-term outcome of both techniques.

Another group of patients who may get benefit from gait analysis is children with Spina Bifida. Spina bifida is a congenital neural tube defect where the spinal column fails to form or close properly in utero, potentially damaging the spinal cord and meninges (Mitchell et al. 2004). Patients with spina bifida exhibit complex gait abnormalities due to varying degrees of lower extremity weakness, paralysis and torsional deformities (Hailey and Tomie 2000; Mitchell et al. 2004). Accurate identification of gait pathologies and their underlying causes is crucial to managing patients with spina bifida and maintaining their ambulatory and functional abilities (Özek et al. 2008). Duffy et al. (1996) investigated gait patterns in 28 children with spina bifida. They found that there were recognisable gait patterns for each level of spina bifida and the that the abnormalities accurately reflected the muscle deficiencies present. The gait patterns approximated more closely to those of the normal group as the neurological level descended. They reported that the most important findings were increased pelvic obliquity and rotation with hip abduction in the stance phase, which is known as Trendelenburg gait pattern, and persistent knee flexion throughout stance due to the absence of the plantar flexion-knee extension. This study provides important information identifying the gait pattern among children with spina bifida that may help clinical providers to understand gait problems and design effective rehabilitation goals to enhance gait.

Moreover, Mueske et al. (2019) investigated the effect of gait analysis data on pathology identification and surgical recommendations in children with spina bifida. Two pediatric surgeons and two physical therapists with more than ten years of experience in gait analysis reviewed the clinical, video, and gait analysis data from 43 ambulatory children with spina bifida (25 males with mean age 11.7 years). Each assessor identified primary gait pathologies before and after considering the gait analysis data. The surgeons also recorded surgical recommendations before and after considering the gait analysis data. Frequencies of pathology and surgery identification with and without gait analysis were compared. The result of this study showed that the pathology identification often changed for common gait problems, including crouch (28% of cases), tibial rotation (35%), pes valgus (18%), excessive hip flexion (70%), and abnormal femur rotation (75%). Recognition of excessive hip flexion and abnormal femur rotation increased significantly after considering gait analysis data ($p<0.05$). Surgical recommendations also frequently changed for the most common surgeries, including tibial derotation osteotomy (30%), anterolateral release (22%), plantar fascia release (33%), knee capsulotomy (25%), 1st metatarsal osteotomy (60%), and femoral derotation osteotomy (89%). At the patient level, consideration of gait analysis data altered surgical recommendations for 44% of patients. Therefore, Mueske et al. (2019) recommended including gait analysis in the patient care process to improve treatment decision making.

As children with Perthes suffer from pain, muscle weakness, and limitation in ROM, their functional activities should be measured biomechanically to assist both surgeon and physiotherapist in setting an optimal rehabilitation programme based on individual needs findings. Lu and Chang (2012) suggest a biomechanical approach to understanding dynamic movement (such as walking), using a motion analysis system to examine the cause of disease, decide on a treatment approach and assess treatment impact. Accordingly, this thesis adopts a biomechanical approach to evaluate functional activities among non-operative children with Perthes to provide essential knowledge about how Perthes disease can affect children's activities. The following section highlights the biomechanics of the hip joint as this is the joint most affected by Perthes disease.

2.9.1 Biomechanics of the hip

Understanding the hip joint mechanics is essential background knowledge for several disciplines, whether these involve clinical diagnosis and management or surgery. It is important to understand how the mechanics of the hip change from the static to the dynamic state of a person, what anatomical structures interact and how these enable movement and maintain stability within those mechanical principles. In addition, it is essential to understand what the normal function of the hip is during daily living activities (Lunn et al. 2016). The following section describes the anatomy and stability of the hip joint.

2.9.2 Hip anatomy

The human hip joint is considered the biggest and most stable joint in the body (Lunn et al. 2016). It consists of two bone parts: the head of the femur and the acetabulum of the pelvis. It is surrounded by a mass of musculature that produces desired movements at both the hip and the knee and prevents unwanted movement from the inertial forces caused by the large movement masses (Lunn et al. 2016). Muscles, however, are not the only important soft tissue structures that influence the integrity of the hip joint. The hip joint has a strong joint capsule and is surrounded by a complex ligamentous structure. The joint capsule has a protective role in restraining the movement of the femur articulating around the acetabulum and preventing dislocation. The extracapsular ligaments comprise the iliofemoral, pubofemoral and ischiofemoral ligaments. These ligaments are passive structures and act like resistance bands to support the hip joint. The configuration of the hip joint (bone, muscle, capsule and ligaments) produces joint stability (Lunn et al. 2016). Hip joint instability will present if any of these components are disturbed or malfunctioning (Levangie and Norkin 2005; Westhoff et al. 2006; Westhoff et al. 2012). It is important to consider the hip joint in both static and dynamic situations to evaluate its stability.

2.9.3 Hip stability

The hip joint has an intrinsic stability factor provided by bone and soft tissues in order to maintain balance and generate movement in both static and dynamic situations (Zaghloul 2018). The stability of the hip joint depends mainly on the ball and socket design (Zaghloul 2018). In addition, the hip bone structure is designed to withstand all stress that is placed upon it during functional activities (Zaghloul 2018). The muscular configuration around the hip joint provides important joint stability during movement. The most important muscles for pelvic stability during single-limb weight-bearing are the hip abductor muscles: the gluteus medius, gluteus minimus and tensor fasciae latae muscles (Levangie and Norkin 2005). These muscles are capable of pulling the rim of the pelvis towards the greater trochanter of the femur during single-limb standing to prevent the pelvis from dropping to the opposite side (Levangie and Norkin 2005). This function is essential for daily functional activities. As an individual walks, the balance should be momentarily maintained over the stance leg while the moving leg swings forward. To prevent pelvic drop onto the opposite leg during the single-leg support phase, the hip abductor muscles (HAMs) should create twice the force produced by body weight to maintain pelvis stability during single-limb support, which is important during daily functional activities such as walking (Levangie and Norkin 2005).

However, patients with Perthes disease demonstrate an abnormally shaped acetabulum and general weakness in the hip muscles, especially in the hip abductor muscle (Pietrzak et al. 2011; Karimi and McGarry 2012). These problems have been reported as the main cause of hip joint instability and pelvic drop to the opposite side during walking, causing limping (Nelitz et al. 2009). Therefore, it is necessary to evaluate the effect of Perthes disease on functional activities for this group of patients. The following section will discuss functional activities and define the terms and tools used to evaluate them to help in understanding movement adaptation among patients with Perthes.

2.10 Functional activities

It is widely recognised that the ability to perform daily functional activities such as walking is adversely affected by lower extremity joint disease (Westhoff et al. 2006; Westhoff et al. 2012). Research into functional activities aims to increase understanding of human locomotion to improve the diagnosis of or set treatment plans for such conditions in the future (Mielke et al. 2013). Patients with Perthes present with pain and limitations of hip joint movement and muscle strength around the hip joint. These symptoms can impact negatively functional activity and decrease patients' levels of independence. Therefore, this section aims to identify the essential functional activities and how they might be evaluated to deeply understand how this group of patients performs daily functional tasks. There is limited work on functional activities among patients with Perthes, and there are no published guides found in the UK that recommend the most important functional activities for patients with Perthes. The only guide found is the Evidence-Based Care Guideline for Conservative Management of Perthes, published by the Cincinnati Children's Hospital (2011). This guideline supports the use of physiotherapy to enhance functional activity among children with Perthes by reducing pain and increasing ROM, by performing muscle strengthening exercises, gait and balance training activities. In addition, the guideline divides Perthes child patients aged between 3 and 12 years into three rehabilitation phases depending on the severity of the disease (based on radiographic data) and specifies different aims and activities for each phase. It divides non-operative children with Perthes into three phases. In the severe involvement phase, it is recommended that the physiotherapist focuses on walking and balance activities. In the moderate and mild involvement phases, a focus on walking, balancing and squatting is suggested. It is believed that these activities are fundamental functional daily activities that help patients to live independently (Bonnechère et al. 2017; Eken et al. 2017; Pirker and Katzenschlager 2017).

As mentioned above, there is limited work evaluating functional activities among children with Perthes. Eight published papers evaluate gait compensation strategies for non-operative children with Perthes, two published work has been found on balance, and there is no published work on squat activities. Therefore, there is a need for more research to understand how non-operative children with Perthes perform during walking, balancing and squatting, to identify the possible challenges that may face children with Perthes disease, and help clinicians and surgeons set effective treatment plans based on patients' abilities in performing functional activities. The following section highlights the importance of the above three functional activities and how children with Perthes may compensate in their movement while performing them.

2.10.1 Walking activity

2.10.1.1 Defining gait analysis

Walking is considered an ordinary activity of daily living that requires all human systems (e.g. musculoskeletal, nervous and cardiorespiratory systems) to work together (Pirker and Katzenschlager 2017). It is described as a repetitive sequence of lower-limb movements that require the body to move forward while maintaining stance stability (Neumann 2013). Gait analysis is the systematic measurement, description and assessment of qualities that characterise human locomotion and evaluate a person's walking pattern (Gage 1995). Moreover, gait analysis involves the measurement of fundamental biodynamic parameters, the compilation of these basic data into an information set, the systematic interpretation of the complied information and the recommendation of treatment alternatives for individual patients on a case-by-case basis (Davis 1997). Based on the Gage (1995) literature, the goals of 'walking' gait analysis are:

1. To describe the difference between the performance of a patient and a healthy subject.
2. To classify the severity of the disease.
3. To determine the efficacy of the intervention.
4. To improve walking performance.
5. To identify the mechanism causing walking dysfunction.
6. To examine the progression of the disease over time.

2.10.1.2 Components of gait analysis

Gait analysis comprises the following components: clinical assessment, temporospatial parameters, kinematic and kinetic parameters, muscle activity measured by electromyogram (EMG) and metabolic energy. In this thesis, only clinical assessment, temporospatial and kinematic and kinetic parameters are considered because of the limited time available for the PhD to consider all gait analysis components.

2.10.1.3 Physical Examination

Physical examination is an integral part of gait analysis and provides measurements of the subject's status at rest prior to performing functional activities. The specific measurements included will rely on the pathology being investigated. They may include passive joint ROM, bone deformity, muscle strength, and contracture. This information will be linked to gait data to help determine the potential causes of the individual's gait deviation. A goniometer measurement provides information about the joint ROM, e.g. whether there is restricted movement in a joint and the degree of limitation. It is essential to evaluate this information as children with Perthes demonstrates limitations in the hip joint. Bone and joint deformity form another essential factor that should be measured. Muscle strength could be measured by several approaches such as manual muscle test or handheld dynamometer (Hébert et al. 2011; Naqvi and Sherman 2021). One noticeable characteristic of walking in children with Perthes is limping due to collapse in the epiphysis. Moreover, measuring muscle strength and contracture in children with Perthes is crucial as they present Trendelenburg's sign due to weakness in the hip abductor muscle and contracture in the hip flexor muscle due to pain in the groin area.

2.10.1.4 Gait cycle

The gait cycle is defined as the time interval between two successive occurrences of one of the repetitive events of locomotion (Ewins and Collins 2013). Each gait cycle is divided into two phases: the stance phase and the swing phase. The stance phase is the period when the foot is on the ground and is 60% of the gait cycle. It begins as the foot touches the floor (foot strike) and finishes when the same foot lifts off to swing (toe-off). The swing phase is when the foot is in the air for limb advancement and is 40% of the gait cycle. It begins when the foot is lifted from the floor (toe-off) and finishes when the same foot strikes the floor (Neumann 2013) (Figures 2 and 3).

The stance phase is subdivided into three periods: initial double support, single-limb stance (or single support) and second double support (or terminal double support). Initial double support starts with the initial foot strike and continues until the other foot lifts to swing (opposite toe-off). Lifting the other foot starts the single support period and continues until the opposite foot contacts the floor (opposite foot strike). Second double support, which is the final stance phase, starts with opposite foot strike and ends with ipsilateral toe-off. The swing phase is also divided into three stages: initial swing, mid swing and terminal swing. Seven events within the gait cycle have been identified by Rose and Gamble (1994): foot strike (or heel strike), opposite toe off, opposite foot strike, toe off, foot clearance, tibia vertical and foot strike. The duration of a complete gait cycle is known as the cycle time (or stride time) (Neumann 2013).

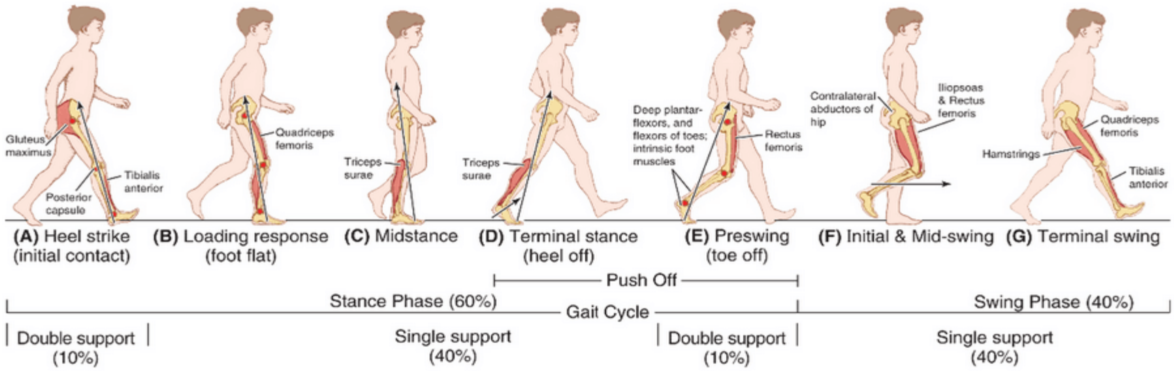


Figure 2: The gait cycle (Neumann 2013)

2.10.1.5 Temporospatial parameters

Temporospatial parameters including walking velocity, cadence, stride length, step length, stride width and percentage of stance/swing are fairly straightforward and easy to acquire in the laboratory and hospital (Lunn et al. 2016). These quantitative parameters provide an indication of the level of function when compared to normal values.

Gait speed is defined as the rate of change in distance with respect to time (speed = distance/time). It is related to both cadence and stride length. Walking speed is referred to as the sixth vital sign (Fritz and Lusardi 2009) since it is a powerful indicator of mobility efficiency (Bjornson and Lennon 2017; Van Ancum et al. 2019). This gait parameter constitutes the most-reported outcome measure of interventions whose aim is to improve gait function (Bjornson and Lennon 2017). It is an easy-to-administer objective and valid measure of walking activity that has been linked to functional ability and quality of life in children with disabilities (Moreau et al. 2016). Step length is defined as the distance between the point of initial contact of the ipsilateral foot and the point of initial contact of the contralateral foot. Stride length is defined as the distance between successive ground contacts of the same foot. Cadence is defined as the rate at which an individual walks; it is expressed in steps per minute.

In terms of gait analysis research, cadence provides information about step frequency (Verghese et al. 2007; Oh-Park et al. 2010; Hollman et al. 2011) and can influence the magnitude of GRF (Castro et al. 2015). Lim et al. (2017) used gait data in conjunction with musculoskeletal modelling techniques to evaluate muscle function over a range of walking speeds using prescribed combinations of step length and step frequency. They found that changes in step length had a greater influence on lower-limb joint motion, net joint moment and muscle function than step frequency. The same authors also identified that peak forces developed by the hip and knee extensors correlated more closely with changes in step length than step frequency. Specifically, increases in step length resulted in larger contributions from the hip and knee extensors. The authors suggest that this may be why patients with weak hip and knee extensors slow their walk by reducing step length rather than step frequency. In addition, Guffey et al. (2016) investigated important gait parameters associated with balance in 84 healthy children (aged 2-4.9 years old) using GAITRite, a walkway that records spatiotemporal parameters and Paediatric Balance Score (PBS) to assess balance. They found that age, leg length, cadence, step/stride length, step/stance time, and single/double support time were significantly correlated with balance score. Guffey et al. (2016) suggest measuring step/stride length, cadence, and leg length for children walking to predict walking stability and balance and provide functional assessment and track improvements during rehabilitation regimens.

Stride time is defined as the time elapsed between foot contact of a leg to the following foot contact of the same leg. It is a trendy measure in gait analysis research, especially regarding gait variability, i.e. the variability between consecutive strides (Hausdorff et al. 1998; Hausdorff et al. 2001; Goldberger et al. 2002).

Step width is the distance between the centres of the feet during double-leg support when both feet are in contact with the ground. In gait analysis research, Kim and Son (2014) have shown that children with spastic diplegic CP walked with a wider base of support in order to stabilize the centre of mass. They found a correlation between step width and walking speed, cadence and stride length. Kim and Son (2014) concluded that children with a wider step width tend to have greater difficulty in gait performance. In addition, Yentes et al. (2017) found that patients with chronic obstructive pulmonary disease (COPD) walk with a narrower step width. The authors suggest that this result may explain the increased prevalence of falls in patients with COPD. It is because step width has been associated with lateral stability (Bauby and Kuo 2000). Maintaining lateral stability during walking is a challenge to the motor control system (Kuo and Donelan 2010). It has been suggested that step width reflects the amount of active control that is required for lateral stabilisation (Bauby and Kuo 2000). Based on this theoretical framework, when lateral foot placement becomes more stable, the required amount of active control decreases (Bauby and Kuo 2000; Donelan et al. 2004). Furthermore, evidence has surfaced to support the link between step width and the risk of falling in older adults (Maki 1997). Step width was able to predict falls (Maki 1997; Hausdorff et al. 2001; Brach et al. 2007) and to differentiate older adults who fell from those who did not fall after a slip (Yang and Pai 2014). Although these quantitative temporospatial walking parameters provide indications of the level of function compared to normal values, they may not indicate the causes of gait deviation. Therefore, considering kinematic and kinetic parameters may provide more information relating to the causes of gait deviation in patients with Perthes disease.

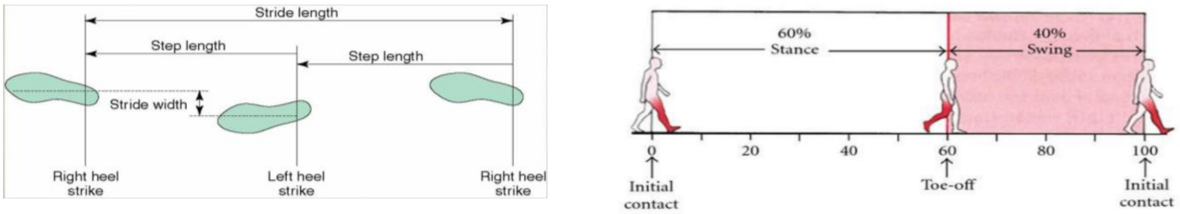


Figure 3: Temporospatial parameters (Baker 2013)

2.10.1.6 Kinematic parameters

Joint kinematics describes the rotational displacement at each joint during walking. Kinematics is defined as the description of the functional activity (such as walking, balancing or squatting) in terms of the angles, displacement, speed and acceleration of the body segments and joints (Kirtley 2006). Kinematic studies have used three-dimensional (3D) motion analysis systems to digitally reconstruct an individual's body as a multisegmented system. Infrared markers are placed at certain anatomic landmarks, and cameras triangulate their positions to calibrate the subject into the system. Construction of the coordinates and orientation of the rigid body segments allow calculation of joint angles of the proximal and distal segments, joint angular velocity and joint acceleration. Measurements are collected for each joint in all three cardinal planes of motion (sagittal, frontal and transverse planes) (Dicharry 2010). The sagittal plane relates to flexion and extension movements of the joint, the frontal plane relates to abduction and adduction movements of the joint, and the transverse plane relates to internal and external movements of the joint (Baker 2013).

2.10.1.7 Kinetic parameters

Joint kinetics provide information about the forces that cause movement. When a force has the effect of producing rotation, the measure of its rotational effect is called a moment of force or "moment" (Perry et al. 2010). The terms "external moment" and "internal moment" are commonly used in movement analysis studies. "When the centre of mass of a body segment is not vertically aligned over the joint, its weight creates a rotatory force that causes the joint to move", and this is called an external moment (Perry et al. 2010). To preserve stability during stance, a muscle response is required to create a counter-moment called internal moment. The external lower limb joint moments are equal in intensity and opposite to the direction of the internal lower limb joint moments (Neumann 2013). Another kinetic term is ground reaction force (GRF), which is equal in intensity and opposite in direction to the forces being generated by the weight-bearing limb and can be measured by force plate systems.

2.10.1.8 Development of gait

Movement control is developed gradually in typically developing children as the brain matures (Griffiths and Clegg 1988). Therefore, the number and complexity of movements that a child makes also increase gradually from birth. Walking, specifically, begins at around one year of age (Griffiths and Clegg 1988; Gage 1991); however, it does not develop into an adult, heel-toe gait until the child reaches three and a half years (Gage 1991). As this thesis includes children over six years old, references to normal gait pattern describe the adult gait.

2.10.1.9 Normal gait

According to Gage (1995), throughout a gait cycle, three tasks must be accomplished. Weight acceptance, the most demanding task in the gait cycle, involves transferring body weight onto a limb that has just finished swinging forward and has an unstable alignment. Shock absorption and the maintenance of a forward progression are also essential components of this phase. The next task of the gait cycle is single-limb support, during which one limb must support the entire body weight and provide truncal support while progression must be continued. The final task of the gait cycle is limb advancement, which requires foot clearance from the floor.

The prerequisites of normal walking (Gage 1995), in order of priority, are:

1. Stability of the entire lower limb in the stance phase.
2. Clearance of the ground by the foot in the terminal swing phase.
3. Proper pre-positioning of the foot in the terminal swing.
4. Adequate step length.
5. Maximisation of energy conservation.

2.10.1.10 Perthes gait abnormalities

Non-operative children with Perthes show gait abnormalities compared to normal gait pattern. First, the stability of the lower limb is affected by Perthes disease and the associated abnormality of femoral head shape, hip abductor muscle weakness and pain in the groin area. Westhoff et al. (2006), Svehlik et al. (2012), Stief et al. (2014) and Karimi et al. (2019) report two distinct patterns among non-operative children with Perthes during the single-limb support. The first is the “Trendelenburg pattern”, which is characterised by pelvic drop towards the non-affected swing limb, increased hip adduction, and trunk lean towards the affected stance limb; the second gait pattern is the “Duchenne pattern”, which is characterised by trunk lean towards the affected stance limb. A second gait deviation involves clearance of the ground by the foot in the terminal swing phase. It is not reported in Perthes literature as a gait deviation; however, the maximum knee flexion in the swing phase is lower on the affected side than on the non-affected limb in patients with Perthes. The third gait deviation involves the proper pre-positioning of the foot in the terminal swing. Yoo et al. (2008) found that non-operative children with Perthes walk in a rotation pattern, either in-toeing or out-toeing, based on the “hump” spatial features on the femoral head. The out-toeing group demonstrated external hip rotation during almost the whole gait cycle, with decreased hip flexion at the initial contact, while the in-toeing group showed internal hip rotation during the whole gait cycle, with decreased hip extension. The fourth gait deviation in non-operative children with Perthes is inadequate step length. Svehlik et al. (2012), Stief et al. (2016) and Karimi et al. (2019) report that Perthes groups walked more slowly than control groups, with short step and stride length. The final gait deviation in children with Perthes involves variations in pelvic rotation, pelvic tilt, knee flexion at midstance, foot and ankle rotation, knee motion and lateral pelvic displacement (Yoo et al. 2008; Svehlik et al. 2012; Westhoff et al. 2012; Stief et al. 2014; Stief et al. 2016; Karimi et al. 2019). These variations in lower limb joints might affect energy expenditure and the mechanical efficiency of walking, as reported in Saunders et al.'s (1953) study.

Despite gait abnormality in children with Perthes being biomechanically considered in the previous literature, little attention has been given to kinetic parameters, especially for knee and ankle joints. Kinetic parameters, especially knee adduction moment, are reported as providing important signs to predict knee degeneration and develop a suitable therapeutic intervention, as suggested in a systematic review (Foroughi et al. 2009). In the previous literature, Westhoff et al. (2006), Svehlik et al. (2012), and Westhoff et al. (2012) recommend performing ipsilateral trunk lean towards the involved side as an unloading mechanism to reduce the load in the involved hip joint. This recommendation may have been made because these researchers considered only the hip joint and paid less attention to knee joints, especially knee adduction moments. Stief et al. (2014) considered knee adduction moment to evaluate the effect of ipsilateral trunk lean on knee joints among 27 children with Perthes. They found that the effect of ipsilateral trunk lean was pronounced in the knee joint and could initiate degenerative changes in knee cartilage. They suggest that ipsilateral trunk lean should not be viewed as an unloading mechanism for the hip joint in isolation but that its potential to cause excess lateral knee joint loading should be considered. It may illustrate why children with Perthes suffer from knee pain, as described previously.

The conflicting recommendations related to trunk leaning may be due to a lack of research investigating walking compensation mechanisms in patients with Perthes. No published systematic review has been found discussing how non-operative children with Perthes might compensate in their walking. Investigating walking compensation mechanisms is essential to enable the clinical community to understand the underlying causes of gait deviation and decide treatment plans to enhance walking. Limited work has been done evaluating gait compensation in non-operative children with Perthes. Additionally, the quality of Perthes walking literature has not been investigated. Therefore, a systematic review that assesses the quality of Perthes walking literature may provide essential information to help the clinical community to understand walking compensation mechanisms and modify treatment strategies deeply. In addition, this systematic review will help the researcher to fill a gap in Perthes walking literature. One of the objectives of this thesis is to undertake a systematic review of the literature on gait compensation mechanisms among children with Perthes.

2.10.2 Single-leg balance activity

Balance is a multidimensional concept referring to the ability of a subject to maintain postural stability and prevent falling (Atwater et al. 1990). Stable postural control is inherently linked to balance, defined as the ability to control the centre of mass in relation to the base of support (Shumway-Cook and Woollacott 2012). Balance is necessary for normal functional activity in all age groups (Franjoine et al. 2010). Balance is inextricably linked to motor development and fundamental movement skills (Fisher et al. 2005). Balance development begins from birth, with typically developing infants mastering standing, then walking, between 10 and 18 months. Pre-schoolers continue to develop the fundamentals of locomotion and motor skills, relying heavily on developing balance, stability and postural control (Shumway-Cook and Woollacott 2012). Children begin to develop adult-like balance at around six to seven years (Nolan et al. 2007). Both static and dynamic, balance can be viewed as a skill acquired through training or play and development. As balance abilities become refined during childhood, the factors influencing balance have been reported to include gender, height, weight and leisure preferences (e.g. basketball and martial arts) (Fong et al. 2012). However, Hadders-Algra (2010) notes that typical human motor development is characterised by variation and the development of adaptive variability. This is observed throughout development, and the variation of acquired skills increases as children develop (Hadders-Algra 2010). Other authors have provided a model for the development of balance strategies adopted by children. One model suggests that children first develop a repertoire of balance strategies and then learn how to adapt those strategies in a task-dependent manner (Assaiante et al. 2005). Acquiring stability and balance involves multiple physiological systems, including the neuromuscular and sensory systems. At a cortical level, the ability to integrate several different signals is a prerequisite for static and dynamic balance (O'Brien 2010). Balance, both static and dynamic, is often assessed to determine the status of neuromusculoskeletal control following lower limb injury as part of a comprehensive assessment of pain, muscle strength and endurance and ROM (Paterno et al. 2010). Single-leg stance (SLS) and tandem stance (TS) are often assessed to ascertain the ability of children (and adults) to maintain balance within a narrow base of support. SLS balance is essential in most functional activities (e.g., walking, during the single-limb stance phase) and evaluates postural balance stability affected by traumatic musculoskeletal injuries (Gribble et al. 2004; Pau et al. 2015; Bonnechère et al. 2017).

In children with Perthes, postural stability may be affected due to the abnormal femoral head shape that affects the stability of the hip joint. In addition, children with Perthes present muscle weakness mainly in the hip abduction responsible for maintaining pelvis stability during walking, in the single-leg support period (Westhoff et al. 2006). Both Hailer et al. (2012) and Hailer et al. (2014) studies found that out of 116 patients with Perthes, 92 had lower limb injuries requiring hospital admission, and 51 had fractures due to decreased muscle strength, hip joint instability, or coordination problems. Although there are indications in the Perthes literature that children with Perthes may have poor postural stability, for example, spending a relatively prolonged time on the stance phase and lowering gait speed compared to control groups (Westhoff et al. 2006; Svehlik et al. 2012), there is only two published work investigating postural stability for Perthes subjects in the static position.

Eliks et al. (2017) investigated postural stability among 19 individuals with structural leg-length discrepancy (LLD) aged between 6 and 30 years. These patients qualified for lengthening surgery with an external fixation approach. Of the 19 patients, 7 acquired LLD due to Perthes disease, while in the remainder, there were other causes such as congenital aetiology. Postural stability was measured in this study by static posturography under two conditions (eyes open and eyes closed) with three different feet positions. The outcome measures considered to evaluate postural stability in the study were velocity of the centre of pressure (COP) and COP path sway in anteroposterior (AP) and mediolateral (ML) directions. The results reveal no significant difference in postural stability between individuals with LLD and those in a control group. The second study investigating postural stability is Karimi and Esrafilian (2013) study. They investigate the postural stability considering the COP parameters among five children with Perthes compared to 10 healthy children standing on force platforms for one minute. They found that children with Perthes were significantly unstable compared to healthy children in the mediolateral of COP direction; they attribute this difference to the weakness of hip muscles surrounding the hip joint in the mediolateral direction.

However, Eliks et al. (2017) and Karimi and Esrafilian (2013) studies have some limitations that should be considered. In Eliks et al.'s (2017) study, subjects had a large age range (from 6 to 30 years) with different conditions and diseases. Moreover, both studies measured postural stability in the static position. The fact that no significant difference was found between the LLD and control groups in Eliks et al.'s (2017) study, even though the patients qualified for lengthening surgery, may be due to the use of low-challenge tasks such as standing in an upright position. Many other balance tasks can challenge subjects in order to examine their ability to control postural stability.

Mani et al. (2019) found that standing on one leg is a more challenging task to measure postural stability among typically developing children aged between three and ten. The study included 48 healthy children aged three to ten who were compared to 11 young adults. The children were divided into four groups by age: three to four, five to six, seven to eight and nine to ten years. An SLS task involved standing on a single leg for up to 30 seconds. The researchers used a 3D motion capture system and two force plates to calculate the centre of mass (COM) and COP. They found that the children did not achieve adult postural control until reaching ten years of age. They conclude that the developmental process of postural control during an SLS task is varied and does not present a monotonic pattern. In another study, Donath et al. (2016) compared different balance activities, including double-limb stance on a foam surface with both eyes open and closed, double-limb stance on firm ground with both eyes open and closed, and SLS on firm ground with eyes open, between 20 healthy young adults with an average age of 24 years, and 20 older adults with an average age of 73 years. They used a force platform to measure postural sway for all subjects during the balance tasks. The results of Donath et al.'s (2016) study reveal that standing on a single leg involved significant postural sway compared to other balance tasks among elderly subjects and compared to healthy young adults. Despite the latter subjects demonstrating lower postural sway in all balance tasks, they exhibited relatively high postural sway in the SLS task compared to the other balance tasks. Therefore, the SLS balance task may be more challenging for children, young adults, and elderly subjects. SLS balance is imperative for an individual to walk independently and should be measured to examine the ability of the subject to control their COM while walking (Mani et al. 2019).

In addition, the outcome measures used to investigate postural stability in both Eliks et al. (2017) and Karimi and Esrafilian (2013) studies are limited. These studies did not consider kinematic and kinetic parameters, which are important to provide information about joint ROM and forces to help in understanding how non-operative children with Perthes might compensate in their movement to maintain postural stability. Therefore, detecting postural balance deficits in non-operative children with Perthes would indicate the need to include balance exercises in rehabilitation management to reduce the risk of injuries and worse scenarios such as a joint fracture.

The literature supports the favourable outcome for balance training among children with an impaired anatomical structure such as juvenile idiopathic arthritis and Down’s syndrome. For example, Baydogan et al. (2015) did a randomized controlled trial to investigate the effect of two exercise programmes on lower extremity function among 30 patients with juvenile idiopathic arthritis. They assessed pain, passive range of motion, muscle strength, balance and functional abilities using the Numeric Rating scale goniometer, handheld dynamometer, Flamingo Balance Test, Functional Reach Test, 10-meter walking test, 10-stair climbing test, and Childhood Health Assessment Questionnaire. Participants were randomly assigned to the strengthening exercise group or balance exercise group. This study found that the balance exercise group significantly improved lower limb extremity function such as walking, climbing stairs, and balance compared to the strengthening exercise group. In another randomized controlled trial study, Gupta et al. (2011) evaluated the effect of exercise training on strength and balance in twenty-three children with Down’s syndrome. Twelve children with Down’s syndrome participated in an intervention group that included progressive resistive exercise for lower limbs and six-week balance training. The control group continued their regular activities followed at school. A handheld dynamometer was used to measure the lower limb muscle strength, and the balance was assessed by the balance subscale of Bruininks Oseretsky Test of Motor Proficiency (BOTMP). The result of the Gupta et al. (2011) study revealed that the children in the intervention group showed a statistically significant improvement ($p<0.05$) in the lower limb strength of all the muscle groups assessed. In addition, the children's balance improved significantly with an improvement in scores of the balance subscale of BOTMP (19.50 in the experimental group versus 9.00 in the control group, $p=0.001$).

Therefore, balance activity should be further investigated among children with Perthes disease to assess their postural stability to avoid injuries and fractures that were reported in Hailer et al. (2012) and Hailer et al. (2014) studies, including COP, kinematic and kinetic parameters. This information regarding postural stability may help clinical providers to focus on balance exercise among this group of patients to enhance their postural stability.

2.10.2.1 Summary of Single leg balance

Mani et al. (2019) and Donath et al. (2016) evaluate different balance tasks to identify which task could be more challenging for children. They found single-leg stance (SLS) is a more challenging task to measure postural stability among typically developing children. In addition, SLS is considered as an essential element in most functional activities (e.g. in walking, during the single-limb stance phase) and provides the evaluation of postural balance stability affected by traumatic musculoskeletal injuries for children and adults (Gribble et al. 2004; Pau et al. 2015; Bonnechère et al. 2017). Children with Perthes demonstrated postural instability related to decreased muscle strength, hip joint instability, or coordination problems (Hailer et al. 2012; Karimi and Esrafilian 2013). Two studies have been identified evaluating postural stability among patients with Perthes disease. Eliks et al. (2017) found no significant difference in postural stability between individuals with LLD (including the patient with Perthes disease) and those in a control group. However, Karimi and Esrafilian (2013) found that children with Perthes presented significantly poor postural stability than healthy children in mediolateral (COP) direction. The contradiction of the result between Eliks et al. (2017) and Karimi and Esrafilian (2013) studies may occur due to Eliks et al.'s (2017) study used an extensive age range (from 6 to 30 years), with different conditions and diseases. Moreover, Eliks et al.'s (2017) study used a low-challenge task such as standing upright, while Karimi and Esrafilian (2013) used more challenging tasks such as standing on one leg. Both Eliks et al. (2017) and Karimi and Esrafilian (2013) studies only considered COP variables to investigate postural stability, while there is no information regarding kinematic and kinetic data. The information of kinematic and kinetic data is essential to provide knowledge of joint ROM and forces to help in understanding how non-operative children with Perthes might compensate in their movement to maintain postural stability. Therefore, this thesis aims to investigate postural stability among non-operative children with Perthes during single-leg balance considering the following parameters: COP, kinematic and kinetic.

2.10.3 Squat activity

Squatting is a multi-joint movement that challenges lower limb muscles throughout the extension chain (Eken et al. 2017). It is frequently performed while doing routine daily activities like sit-to-stand (Stevens et al. 2018). In addition, it is used as a feasible assessment tool in the consultation room to provide a good indication of lower extremity muscle strength and joint stability (Horan et al. 2014). The squat movement is described based on the position of the legs relative to the ground, the location of weight during loaded squats and the degree of knee flexion (Stevens et al. 2018). There are three stages to squatting: the start of the squat (when the hips and knees are fully extended), the squat (when participants reach their squat capacity depth) and the ascent (when participants return to the fully upright position) (Stevens et al. 2018). The literature shows that squat activity becomes more considered in orthopaedic and neurological paediatric patients (Ugalde et al. 2015; Weeks et al. 2015). Eken et al. (2017) examined whether a squat test is suitable for determining lower limb strength for children with cerebral palsy (CP) and typically developing children. The squat test is defined as the number of squats performed. The starting position of a squat was standing upright. Subjects were instructed to squat as deep as possible, defined as maximal knee flexion while keeping the trunk upright and standing up again. The Eken et al. (2017) study found that squat test performance was reduced in children with CP, especially those with severe CP. They conclude that the squat test is feasible for testing lower limb strength in children with CP in a clinically meaningful way. Moreover, Eken et al. (2020) evaluated the validity and reliability of a squat test in children with CP. They examined children with CP via two trials of a squat test and calculated the intraclass correlation coefficient to evaluate intraobserver reliability. Correlation between handheld dynamometry (HHD) outcomes for knee extensor strength, eight-repetition maximum (8RM) leg press test and squat test were calculated to measure the construct validity. The results revealed excellent intraobserver reliability as demonstrated ICC=0.935 [0.878- 0.966], and good construct validity as showed Pearson correlation coefficient (r) for the maximal number of squats and HHD (in Nm/kg) r = 0.652 and the maximal number of squats and 8RM leg press (% of body weight) r = 0.902. Therefore, the squat test is a reliable and valid tool to assess lower limb strength in children with CP. The advantages of the squat test are that it is inexpensive and not time-consuming, and therefore particularly suitable for use by clinicians. However, no literature has been found discussing how children with Perthes disease perform during squat activities. Perthes disease affects ROM and muscle strength around the hip joint; it has been assumed that squat activity performance would involve compensation and deviation. This assumption will be confirmed in chapter five of this thesis.

2.10.4 Summary of functional activities

Children with Perthes express pain associated with functional activities such as walking. Pain is not the only factor that could lead to movement compensation; muscle weakness (especially of the hip abductor muscle) and abnormal hip joint shape are other possible factors. There is limited published work on compensation-movement strategies during walking, single leg balance and squat activities in non-operative children with Perthes disease. These three functional activities have been recommended for non-operative children with Perthes disease based on the Evidence-Based Care Guideline for Conservative Management of Perthes, published by the Cincinnati Children's Hospital Medical Center in (2011). It is believed that these activities are fundamental functional daily activities that help individuals to live independently (Bonnechère et al. 2017; Eken et al. 2017; Pirker and Katzenschlager 2017). Despite the walking activity has been considered in this group of patients, the quality of walking literature has not been considered. In addition, the single-leg balance literature has been investigated in two studies, and the result was contradicted due to the number of limitations such as a low-challenge task such as standing in an upright position in Eliks et al. (2017) study. Both Eliks et al. (2017) and Karimi and Esrafilian (2013) studies only considered COP variables to investigate postural stability during balance activity, while there is no information regarding kinematic and kinetic data.

Moreover, no literature has been found discussing how children with Perthes disease perform during squat activities. Perthes disease affects ROM and muscle strength around the hip joint; it has been assumed that the three functional activities performance would involve compensation and deviation. This assumption will be confirmed in this thesis.

2.11 Quality assurance of biomechanical movement data

It is essential to establish the reliability of measurement techniques and methods of quality assurance to ensure that the very highest standards of reliability are achieved (Baker 2006). Baker et al. (2006) state two principal sources of error that affect movement data quality. The first source of error involves the challenge of identifying the anthropometry of the individual subject (which is known as model calibration), including placing markers accurately with respect to specific anatomical landmarks, and determining the location of joint centres (and other anatomical features) in relation to these markers. The second source of error is the degree of movement of the skin, muscle and other soft tissues in relation to the bones during movement. These two sources of error associated with collecting biomechanical movement data were supported by Taylor et al. (2005), Sangeux et al. (2011), and Kratzenstein et al. (2012). To resolve these issues with movement data, Baker et al. (2013) suggest checking the reliability of marker placing to ensure the researcher's reliability in placing markers on subjects. In addition, Baker et al. (2013) recommend checking the reliability of walking data as children may change their walking patterns, influencing gait outcomes. Therefore, this thesis aims to establish the reliability of the researcher on placing the marker on subjects and establish the reliability of typically developing children walking as the method for this thesis to identify the sources of error associated with collecting biomechanical data in order to obtain good quality of movement data.

2.12 Level of Physical Activity, Quality of life and Management of physiotherapy treatment among non-operative Children with Perthes

Relying solely on biomechanical data is not enough to understand the difficulties patients with Perthes may face in life. It is recommended that the physiotherapists require several types of information: that which is relevant to diagnosis, prognosis, and biomedical knowledge of the body and information on the experience of living with impairments and managing physiotherapy (Shaw et al. 2012). This section is divided into two subsections. The first subsection has discussed the level of physical activity and quality of life, while the second subsection discusses the importance of considering management of physiotherapy treatment among non-operative children with Perthes.

2.12.1 Level of Physical Activity, Quality of life among non-operative Children with Perthes

In the early stage of Perthes disease, children with Perthes complain of pain mainly after doing physical activities, leading to physical inactivity. After diagnosis with Perthes disease, patients receive behavioural advice for daily life, including reducing certain physical activities that may generate peak impact loads for the hip joint, for example, running and jumping (Palmen et al. 2014). These restrictions may lead to increase body weight due to physical inactivity. In Neal et al.'s (2016) retrospective cohort study, which included 150 patients with Perthes (172 hips) observed between 2009 and 2014, researchers found that obesity is common among patients with Perthes (16% overweight, 32% obese). The manifestation of obesity could result from physical inactivity that may lead to mental and social problems among these patients. Kohl et al. (2013) reported that physical inactivity might affect mental health and other aspects of well-being. In addition, Hailer et al. (2014) found that lack of mobility (such as walking), pain and anxiety/depression are associated with Perthes disease and negatively affect the general quality of life. Similarly, Leo et al. (2019) report that pain, impact on sleep and restrictions on playing and school attendance are possible causes of lower quality of life among children with Perthes. Perthes disease impacts children with Perthes and negatively affects their parents and siblings (Leo et al. 2019).

There is a lack of work on quality of life for children with Perthes. Three published studies have been found reporting quality of life among patients with Perthes (Hailer et al. 2014; Palmen et al. 2014; Leo et al. 2019). Hailer et al. (2014) investigated whether individuals with Perthes have a high risk of attention deficit hyperactivity disorder (ADHD), depression and mortality. They included 4,057 patients with Perthes in Sweden during 1964 - 2011 and 40,570 healthy control from the Swedish general population and were matched by year of birth, sex and region. They found that individuals with Perthes presented a high risk of ADHD, depression, and mortality risk such as cardiovascular disease. This study did not provide clear information regarding the age and medical history of individuals with Perthes, whether they had fractures or surgery in lower limbs as consequences of Perthes disease.

Palmen et al. (2014) investigated the quality of life for post-operative children with Perthes. They used the KIDSCREEN-10 and the modified Harris Hip Score (mHHS) questionnaire, including 17 children aged 5 to 11 years at the time of surgery, to investigate health-related quality of life (HRQoL). Analysis of mHHS was made preoperatively, and the time of the follow-up examination was at least two years postoperatively. The follow-up results were compared to an age-matched normal control group. The result of this study revealed that children with Perthes had a higher T-value of the KIDSCREEN- 10 (70.2±12.7) than the mean T-value of the control group (56.6±10.4). The mHHS improved from (54.4±19.9) to a score of (99.5±1.5) postoperatively. However, this study had a number of limitations that should be considered. The inclusion criteria were not clearly described; they included twenty-four patients out of 43 with no clear information regarding the eligibility criteria. In addition, there is no information regarding who was completed the questionnaire, whether parents or children. The other limitation in Palmen et al. (2014) study is that the healthy control group was recruited from a heterogeneous pool; thus, the control group might pay less attention when they completed the questionnaire as the result of the KISDCREEN was low by approximately 14 scores compared to children with Perthes disease.

Leo et al. (2019) investigated the social, physical, and emotional impact of living with Perthes' disease on affected children and families. Eighteen parents and twelve children with Perthes (mean age= 7.1 years) were interviewed. Thematic analysis of the parent interviews revealed that pain, the impact of sleep and school attendance was a marked effect on their children. In addition, the interviews showed a negative effect on the family life of the parent and siblings. Children with Perthes indicated that activities of daily living were affected even during good days, and the pain was the key limiting factor. The authors concluded that Perthes' disease negatively affects children's social, physical, and emotional well-being and families. However, this study by Leo et al. (2019) did not give information regarding the severity of Perthes disease and whether the children with Perthes had surgery or not. They recruited patients from a single centre, which induces limitations related to small sample size and poor patient's diversity.

As the previous three works did not investigate the quality of life among non-operative children with Perthes, this thesis aims to fill this gap of knowledge by investigating the quality of life among this group of patients to understand the disease condition better.

2.12.2 Managing physiotherapy treatment

Another important information for physiotherapists to understand the disease condition is to understand how patients with Perthes disease and their families could deal with physiotherapy management. This type of information is crucial to increase adherence to physiotherapy management (Birt et al. 2014; Goodfellow et al. 2015). Despite the importance of evaluating adherence to physiotherapy treatment, no study has been found on Perthes disease; only a small body of related literature exists regarding patients with hypermobility and cystic fibrosis. Birt et al. (2014) investigated adherence to home physiotherapy management in children and young people with joint hypermobility. They interviewed 19 patients aged between 5 and 17 years and 28 families. Both patients and their families expressed that exercise reduced the symptoms of hypermobility. Parental motivation, adapting family routines, making exercise a family activity and seeing benefits increased adherence to exercise. Non-adherence to exercise was linked to lower levels of parental supervision, not understanding the treatment, not seeing benefits and not having specific times dedicated to doing the exercises. Goodfellow et al. (2015) evaluated adherence to chest physiotherapy management in children with cystic fibrosis and parental beliefs about receiving physiotherapy management. The study included 100 children with cystic fibrosis (≤ 18 years) and their parents. Adherence to chest physiotherapy management was assessed using a general practitioner’s prescription issue data; beliefs about treatments were assessed using refined versions of the “beliefs about treatment questionnaire”. The results reveal that 49% of those surveyed were low adherers to chest physiotherapy management. Parental beliefs on the necessity of treatment and child age were significant independent predictors of child adherence to chest physiotherapy, but parental depressive symptoms were not predictive of adherence.

Based on previous literature that discusses adherence to physiotherapy management among children with different conditions, it is essential to look into these factors among non-operative patients with Perthes in order to obtain an indication of how they manage physiotherapy treatment as no literature has been found. A relationship has been found (for children with cystic fibrosis) between high adherence to physiotherapy management and parental belief in the importance of treatment (Murray, 2005; Goodfellow et al. 2015). Therefore, future research is necessary to understand the quality of life experienced by non-operative patients with Perthes and their parents and how they manage physiotherapy treatment in order to reduce unfavourable results such as delayed progress, avoid unnecessary changes of the management plan and decrease unfavourable clinical outcomes (Chappell et al. 2002).

2.13 Conclusion

Legg-Calve-Perthes Disease is defined as a lack of blood circulation in the femoral epiphysis because of idiopathic osteonecrosis of the femoral head. It is associated with pain, limited ROM, muscle weakness and instability in the hip joint (Karimi and McGarry 2012; Svehlik et al. 2012). These identified problems associated with Perthes disease lead to gait compensation and sign of poor postural stability (Westhoff et al. 2006; Westhoff et al. 2012; Karimi and Esrafilian 2013; Stief et al. 2014). However, there is a contradicted recommendation regarding the trunk lean to reduce hip loading on affected Perthes limb during walking (Westhoff et al. 2006; Svehlik et al. 2012; Westhoff et al. 2012; Stief et al. 2014), this may be due to a lack of systematic review research. Therefore, one of the objectives of this thesis was to conduct a systematic review study to investigate walking compensation mechanisms which are essential to understand the underlying causes of gait deviation and design the method for this thesis by identifying the knowledge gap in the Perthes literature. In addition, there is limited work investigating how children with Perthes could perform during single-leg balance and squat activities, which are fundamental tasks for daily life activity (Franjoine et al. 2010; Children and Medical Center 2011; Stevens et al. 2018). This thesis also aims to investigate the compensation-movement strategies during single-leg balance and squat activities to provide essential information to help the clinical community understand compensation mechanisms during these activities. Before collecting biomechanical data from children with Perthes, the researcher needs to establish the reliability study on placing markers and the reliability of typically developing children walking to reduce the sources of error associated with collecting movement data, as suggested by Baker (2006). Biomechanical data alone is insufficient to understand the difficulties that may face patients with Perthes in the course of their lives. Children with Perthes receive behavioural advice for daily life, which may lead to increased body weight due to physical inactivity and poor quality of life (Palmen et al. 2014). However, the Perthes literature that investigated the level of physical activity and quality of life among non-operative children with Perthes is limited. No previous study has been found evaluating how children with Perthes and their families manage the physiotherapy treatment. Therefore, this thesis aims to investigate the level of physical activity, quality of life, and how non-operative children with Perthes manage physiotherapy treatment. These thesis aims might provide essential knowledge to build a good understanding of the effects of the Perthes disease. In order to fill these evidence gaps, this thesis will address the following aims and objectives.

2.14 Aim and objectives

2.14.1 Aim

The overall aim of this thesis is to develop an improved understanding of the effect of Perthes disease on functional activities, physical activity level and quality of life and of the management of physiotherapy treatment in non-operative children with Perthes to help clinical providers set optimal rehabilitation goals.

2.14.2 Objectives

1. To systematically review Perthes gait literature's quality and identify the movement-compensation strategies in non-operative children with Perthes during functional activities.
2. To evaluate how non-operative children with Perthes perform during walking, single-leg balance and squat.
3. To evaluate the physical activity level and quality of life between non-operative children with Perthes and typically developing children.
4. To evaluate how non-operative children with Perthes and their families manage the physiotherapy treatment.

This thesis is comprised of two studies. Study one, a systematic review, addresses objective one. Study two, an evaluation of compensation strategies in functional activities, level of physical activity, quality of life and management of physiotherapy treatment for non-operative children with Legg-Calve Perthes disease, addresses objectives two to four.

Chapter Three: Study one

Gait compensation among children with non-operative Legg-Calve-Perthes disease: A systematic review

3.1 Introduction

Walking is the essential functional daily activity, and an inability to walk can drastically change a person's life and decrease their level of independence (Pirker and Katzenschlager 2017). The gait abnormality can be defined as a deviation from normal walking (Lehmann et al. 1992). Normal gait can be altered when a patient experiences an injury or pain, resulting in abnormal walking, leading to significant health issues. Examples of such health issues include musculoskeletal problems resulting from altering movements to compensate for pain and discomfort, cardiovascular problems and increased body weight due to inactivity, and mental health problems such as depression due to loss of independence (Pirker and Katzenschlager 2017). Hailer et al. (2010) and Mörlin and Hailer (2021) found that patients with Perthes disease demonstrated a higher prevalence of cardiovascular disease than healthy individuals due to increased body mass and physical inactivity. In addition, Dumurgier et al. (2009) attributed the physical inactivity level to slow walking speed in older people, strongly associated with an increased risk of cardiovascular mortality. Dumurgier et al. (2009) investigated the relation between low walking speed (as a gait deviation) and the risk of death in 3208 elderly subjects aged over 65 years older. They found that 59 out of 209 individuals died from cardiovascular disease related to physical inactivity. Older people in the lowest third of baseline walking speed had an increased risk of death (hazard ratio 1.44, 95% confidence interval 1.03 to 1.99) compared with the upper thirds. Analyses for specific causes of death demonstrated that individuals with low walking speed had a threefold increased risk of cardiovascular death (2.92, 1.46 to 5.84) compared with individuals who walked faster (Dumurgier et al. 2009). Therefore, it is crucial to conduct the gait analysis to determine movement abnormalities causing pain and set optimal treatment plans to correct these abnormalities (Gage 1995). Gait training has been recommended as an effective intervention to improve walking ability, including walking speed in children with CP and spina bifida (Cho et al. 2016; Moreau et al. 2016; Booth et al. 2018; Mueske et al. 2019). A systematic review study, Richards et al. (2017) provided an example of how gait training may enhance gait function and reduce pain among patients with osteoarthritis. This review found that gait training effectively reduces knee adduction moment, reduces pain, and improves gait function by redistributing the load over the knee cartilage in patients with knee osteoarthritis.

As discussed in the literature chapter, children with Perthes present movement-compensation during walking, possibly due to pain in the groin area, muscle weakness, limited ROM and abnormality in the shape of the hip joint. These problems might lead to gait alteration in the hip joint and other lower limb joints and trunk in three planes of movement (sagittal, frontal and transverse). However, the Perthes gait literature presents conflicting recommendations with regard to trunk leaning position during walking (Westhoff et al. 2006; Svehlik et al. 2012; Westhoff et al. 2012; Stief et al. 2014). These conflicting recommendations may be due to the lack of a systematic study that critiques and synthesises findings on gait compensation among non-operative children with Perthes. Therefore, a need remains to understand how non-operative children with Perthes compensate in their walking to help clinical providers set rehabilitation goals based on the difficulties in walking that non-operative children with Perthes may experience.

3.1.1 Study objectives

The objectives of this systematic review are to investigate the quality of Perthes gait literature, to identify the gait compensation strategies presented in the Perthes gait literature, and identify a knowledge gap.

3.1.2 Research question

1) What is the quality of Perthes gait literature?, 2) What are the gait compensation strategies among children with non-operative Perthes disease in sagittal, frontal and transverse planes?, 3) What is the knowledge gap?

3.2 Methods

3.2.1 Search strategy

A population, intervention, comparison and outcome (PICO) approach was utilised. The PICO format help to develop a well-formulated research question based on the problems faced in research activities and clinical practice (Aslam and Emmanuel 2010). The PICO format provides important information to decide whether the topic is relevant, researchable, and significant. Therefore, this systemic review used the PICO format to design the research question. The population in this study comprised non-operative children with Perthes. The intervention was the motion analysis technique, the comparison was made with typically developing children (if found), and the outcome was gait parameters including temporospatial, kinematic and kinetic in three planes (sagittal, frontal and transverse). An electronic literature search was conducted to provide a comprehensive overview of gait compensation to ensure that no articles were missed. The databases used were MEDLINE, CINAHL, PubMed, and the Cochrane Library, using the search services Ovid, EBSCO Host and Embase of Knowledge from inception to August 2020. The search strategy targeted the categories title, abstract and terms (Table 3). Wildcard symbols were used to retrieve all possible suffix variations of the root words. The search was restricted to the English language (appendix i).

Table 3: Search terms based on PICO format

Population	Intervention	Comparison	Outcome
Perthes, necrosis, hip pathology	three-dimension motion analysis, two-dimensional movement analysis	typical development child*	gait, walking, locomotion, ambulation, mobility
non-operative, non-surgical	gait analysis	healthy child*, healthy paediatric	compensate*, adapt*, deviate*, variation, alter*, change*
kid, girl, boy, adolescent, paediatric, child*	motion capture		temporospatial, kinematics, kinetics

3.2.2 Inclusion/exclusion criteria and screening

Two independent reviewers (R.A and M.G) screened the title and abstract of each study, and full texts were subsequently retrieved and evaluated for definitive inclusion if they met the inclusion criteria (Table 4). The R.A is an Assistant Professor in Biomedical Engineering at The Hashemite University, and the second reviewer (M.G) is also an Assistant Professor in Paediatric Physiotherapy at Umm Al-Qura University. Both reviewers have PhDs. This review focused on studies involving a group of non-operative children with Perthes walking with abnormal gait patterns and a group of normal control subjects, quantified by means of a marker-based three-dimensional or two-dimensional motion analysis system. The grey literature such as conference abstracts, non-peer-reviewed publications, secondary literature has been excluded. Although this grey literature is an important source of information for large-scale review syntheses, it will not be easy to search systematically, as Godin et al. (2015) reported. Therefore, the grey literature has been excluded in this systematic review study.

Table 4: Inclusion and exclusion criteria for Perthes walking literature

Category	Inclusion	Exclusion
Type of study	Published in peer-reviewed scientific journals	Conference abstracts, non-peer-reviewed publications, secondary literature
Main outcomes	Clearly identified gait data; data had to be retrieved from skin-mounted markers by means of at least two-dimensional kinematic data	Single video data without markers
Subjects	Human cohorts presenting pathological gait pattern with group-average age between 5 to 12 years	Surgery in the lower limb, Parkinson’s disease (due to bradykinesia), Down’s syndrome (due to complex cognitive impairments), obesity (due to inaccurate placement of markers)
Measurement conditions	Walking on level ground or treadmills with a smooth surface and without any obstacles	Stair climbing, walking uphill or downhill, walking on uneven ground or a slippery surface
Walking characteristics	Subjects walked freely without any kind of walking aid at either normal (self-selected), fast, slow or default (e.g. paced) gait speed and either barefoot or in normal footwear (e.g. flat-heeled shoes)	Running studies, special footwear

3.2.3 Quality assessment and Data extraction

The validity of the finding of the systematic review study depends on the methodological quality of the individual studies in which they are included (Whiting et al. 2017). Therefore, evaluating the quality of included studies is an integral component of a systematic review (Whiting et al. 2017). As standardized tools should accurately evaluate the quality of the studies, many tools have been designed in the recent year, such as Cochrane Collaboration, GRADE tool, Newcastle-Ottawa Scale (NOS), the CONSORT and PRISMA tools (Negarandeh and Beykmirza 2020). Whiting et al. (2017) stated that there are many quality assessment (QA) tools that make it difficult for the researchers to choose the most appropriate tool for use in their reviews. In addition, Negarandeh and Beykmirza (2020) reported that several systematic review studies used CONSORT or other similar checklists such as PRISMA as a tool for assessing the quality of primary included studies. However, these tools have been formulated to improve the quality of reporting, and the researchers are recommended that not using the CONSORT and PRISMA as the quality assessment tools (Negarandeh and Beykmirza 2020). Therefore, the QA tool should be relevant to the type of studies which will be included in the systematic review.

To determine the relevant QA tool for this systematic review, the Downs and Black checklist has been considered. The downs and black (1998) checklist has been used in many healthcare systematic review studies to assess the quality of including studies that aimed to investigate the gait function of different disease/disorder conditions (Simic et al. 2010; Schmid et al. 2013; Morgan and McGinley 2014; Phillips and McClinton 2017; Springer and Khamis 2017). The Downs and Black (1998) showed to have good inter-rater reliability (r = 0.75) as well as high internal consistency (KR-20: 0.89). Since, however, the included articles in the current study did not focus on treatment interventions, the checklist was adapted based on Schmid et al.'s (2013) suggestion. Schmid et al. (2013) examined and cross-validated an adapted Downs and Black checklist with four independent reviewers; they recommend using the adapted Downs and Black checklist for similar work.

The adapted Downs and Black checklist consisted of 17 items with a maximum score of 20 points, including the five different categories ‘‘quality of reporting’’ (eight items, maximum 10 points), ‘‘external validity’’ (three items, maximum three points), ‘‘internal validity – bias’’ (three items, maximum three points), ‘‘internal validity – confounding’’ (two items, maximum two points) and ‘‘statistical power’’ (one item, maximum two points). Subsequently, the checklist was included in the data extraction sheet (appendix ii). All quality assessment data were extracted by R.A and M.G. they did not know each other, eliminating any potential for bias. The reviewers received the relevant Perthes gait literature and modified the Downs and

Black checklist by email in Excel format (the lead project researcher). The lead project researcher described how to use the checklist to the reviewers and encouraged them to ask questions to clarify any possible issues. Any disagreements were discussed to ensure consistency in the interpretation of scores. The extracted data presented in this systematic review include subject characteristics, methodological data and gait compensation for children with non-operative Perthes disease in sagittal, frontal and transverse planes.

3.2.4 Analysis

Percentage agreement and nominal kappa statistics with bootstrapped bias-corrected 95% confidence intervals (CI) were used to ensure the overall agreement of the two independent raters in the QA (Alle et al. 2008). Kappa values were calculated using the command ‘‘crosstab” in IBM SPSS software Statistics for Windows, version 25 (IBM Corp., Armonk, N.Y., USA) (Gouda 2015). Mean values along with standard deviations (SD) were calculated for the summarised scores in each of the QA categories to assess the overall quality of the included studies (Schmid et al. 2013). Meta-analysis of extracted data was not possible due to heterogeneity of the gait outcome measurements.

3.3 Results

3.3.1 Selection of studies

The electronic database search yielded a total of 277 papers. After removing duplicates, congress proceedings, non-peer-reviewed publications, secondary literature and reviews, 210 studies were included for the title and abstract screening. Following this step, 13 full texts were retrieved and evaluated, of which eight articles met all the inclusion criteria (Figure 4).

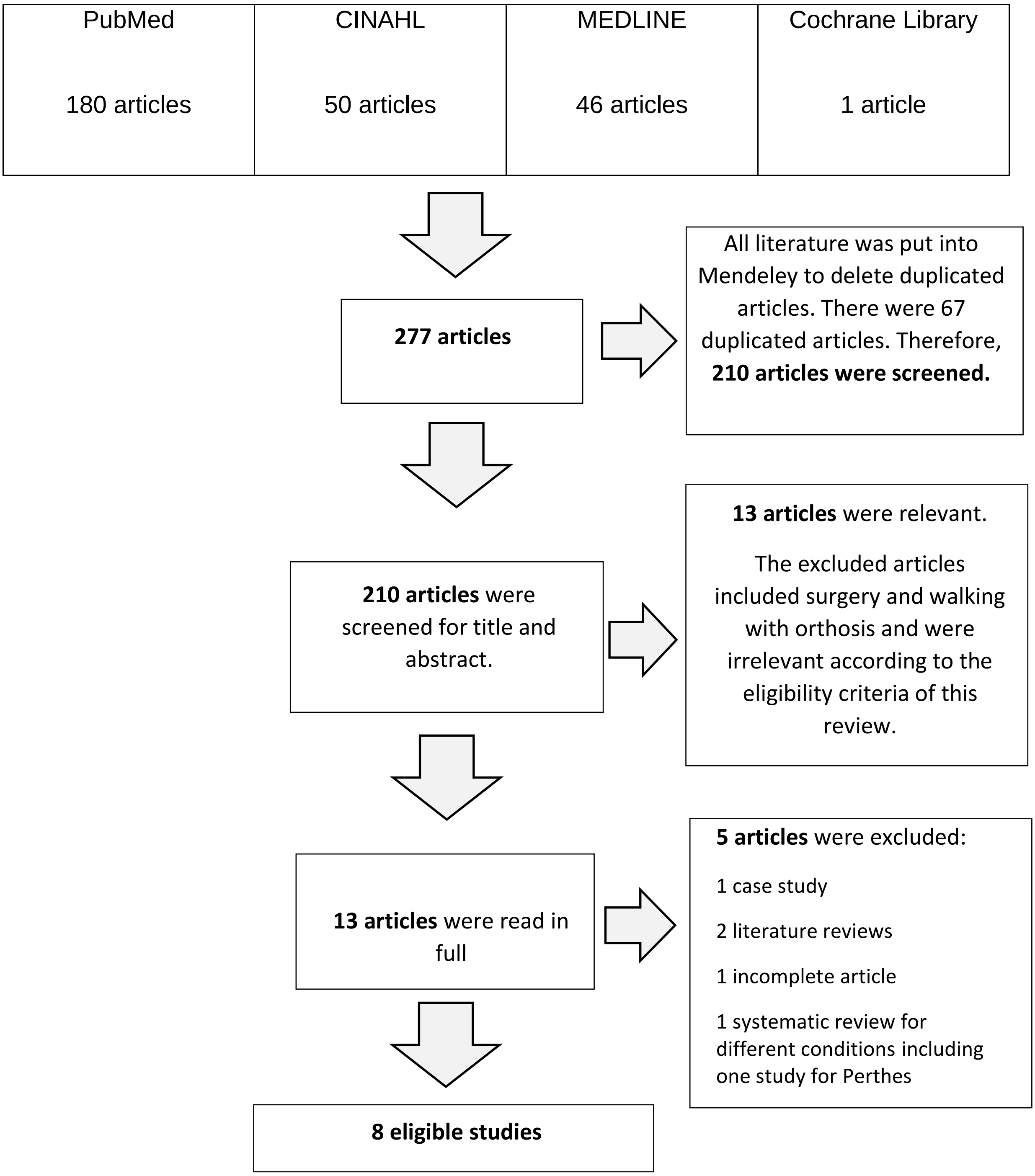


Figure 4: Flow chart of systematic search

3.3.2 Methodological quality

The analysis of the overall agreement between two independent raters performing QA on literature in this review revealed that a percentage agreement of 95% and a Kappa value of 0.906 (95% CI: 0.84–1), indicating an ‘‘almost perfect’’ agreement between the two independent raters based on Landis and Koch's (1977) study. The results of the modified Downs and Black checklist are presented in Table 5. The follow-up studies are all based on a 100% agreement between the two independent reviewers (R.A and M.G). For four studies (Westhoff et al. 2006; Yoo et al. 2008; Svehlik et al. 2012; Westhoff et al. 2012), the items on reporting gait analysis methods had to be rated as only ‘‘partially described’’ due to lack of, for example, statistical information, patient characteristics, measurement device information regarding marker placement and device frequency, and reporting of the principal confounding factors (e.g. weight, height and sex). In addition, Yoo et al. (2008) did not provide the actual probability value as they did not include a control group. The identification of the source of control population had to be rated ‘‘Unable to determine’’ in all the studies. Another weakly scored item was the one reporting on staff, places and facilities for the measurements. None of the eight papers identified where the measurements took place or what the profession of the examiner was, but the item was scored as 1 (“Yes”) when a laboratory was mentioned in the article or the affiliation. Finally, no study reported on the inclusion of a power analysis (a priori or post hoc) and the respective effective power values.

Table 5: Results of study quality rating by reviewers R.A and M.G

First author	**Reporting**		**External validity**		**Internal validity (bias)**		**Internal validity (Confounding)**		**Power**		**Total score**	
	R.A	M.G	R.A	M.G	R.A	M.G	R.A	M.G	R.A	M.G	R.A	M.G
Westhoff (2006)	9	9	1	1	3	3	2	2	0	0	15	15
Yoo (2008)	7	7	1	1	2	2	2	2	0	0	12	12
Svehlik (2012)	9	9	2	2	2	2	2	2	0	0	15	15
Westhoff (2012)	9	9	1	1	3	3	1	1	0	0	14	14
Stief (2014)	10	10	2	2	2	2	2	2	0	0	16	16
Stief (2016)	10	10	3	2	2	2	2	2	0	0	17	16
Stevens (2019)	10	10	2	2	2	2	2	2	0	0	16	16
Karimi (2019)	10	10	1	1	3	2	2	2	0	0	16	15
Total for each category Mean (±SD)	9.25 (± 1)		1.5 (± 0.6)		2.3 (± 0.4)		1.8 (± 0.3)		0		15 (±1.4)	

3.3.3 Methodological data

The extracted data (subject characteristics, methodological data and gait compensation) are presented in Table 6. The included studies contained the condition of Perthes disease and used movement analysis systems to evaluate walking patterns. The age range of the patient groups was between 6 and 11.5 years, with an overall average group age of 8 years.

Regarding the measurement conditions, six studies reported temporospatial parameters that indicate that patients walked more slowly than control group subjects (Westhoff et al. 2006; Svehlik et al. 2012; Stief et al. 2014; Stief et al. 2016; Karimi et al. 2019; Stevens et al. 2019). However, neither Westhoff et al. (2012) nor Yoo et al. (2008) provided information on temporospatial parameters. Three studies reported that the subjects walked barefoot (Westhoff et al. 2006; Westhoff et al. 2012; Stief et al. 2016), while four studies provided no information about footwear (Yoo et al. 2008; Svehlik et al. 2012; Stief et al. 2014; Karimi et al. 2019).

Only three studies considered measuring and comparing both affected and non-affected limbs of patients with Perthes (Yoo et al. 2008; Westhoff et al. 2012; Stevens et al. 2019). The remaining five studies provided no clear information on whether the affected side evaluated was the right or left. Four studies included evaluation of the ankle joint (Yoo et al. 2008; Svehlik et al. 2012; Stief et al. 2014; Stevens et al. 2019), five studies considered the knee joint (Svehlik et al. 2012; Westhoff et al. 2012; Stief et al. 2014; Stief et al. 2016; Stevens et al. 2019). All studies considered the hip joint; seven studies considered the pelvic joint (Stevens et al. (2019) was the exception), and five studies considered the trunk segment (Westhoff et al. 2006; Westhoff et al. 2012; Stief et al. 2014; Stief et al. 2016; Karimi et al. 2019). Overall, one study evaluated two joints (Yoo et al. 2008), three studies evaluated three joints (Westhoff et al. 2006; Karimi et al. 2019; Stevens et al. 2019), and four studies evaluated four or more joints (Svehlik et al. 2012; Westhoff et al. 2012; Stief et al. 2014; Stief et al. 2016). All studies considered both kinematic and kinetic parameters, except Yoo et al.'s (2008) study, which considered only kinematic parameters. A summary of compensatory gait mechanisms in relation to the biomechanical constraints of the primary pathologies and the frequency of gait outcome measurement reported in Perthes gait literature are presented in Tables 6 and 7.

Table 6: Overview of gait compensation literature

Study	Diagnosis	Number of subjects (gender)	Mean age in years (±SD)	Parameters evaluated	Joints evaluated	Outcome parameters	Perthes outcome Mean (± SD)		Control outcome Mean (± SD)	p-value	Gait Compensation
1) Westhoff et al. (2006)	A diagnosis of Perthes with unilateral involvement was confirmed on radiographs.	Control: 30 (14 boys, 16 girls) Perthes: 33 (24 boys, 9 girls)	Control: 8.1 (± 1.2) Perthes: 8.0 (± 2.0)	Temporospatial, Kinematic and Kinetic	Thoracic, spinal, pelvic and hip	Gait speed (m/s)	1.08 (± 0.19)		1.18 (± 0.18)	p = 0.045	Temporospatial data: The Perthes group showed significantly lower gait speed and short stride length compared to controls. The stance phase time was higher in the Perthes group than in the control group. Kinematics data: There are two different gait patterns in the frontal plane among children with Perthes. Type 1 gait (Trendelenburg) pattern is characterised by a pelvic drop to the swinging limb, increased hip adduction, and trunk lean to the stance limb in relation to the pelvis. Type 2 gait (Duchenne) pattern is characterised by trunk lean towards the affected stance limb. Kinetics data: Type 1 showed increased abductor hip moment to a greater extent than control and Type 2 Perthes groups. Type 2 demonstrated a significant reduction of the hip abductor moment in the single stance phase.
						Stride length (m)	0.74 (± 0.07)		0.8 (± 0.06)	p = 0.001	
						Stance phase (s)	59 (± 2.2)		58.3 (± 1.2)	p = 1.18	
						At single-limb stance	Type 1 _ Type 2				
						Thorax obliquity ROM°	-4.3 (± 5.7) _ -5(± 1.9)		-0.8 (± 1)		
						Pelvic obliquity ROM°	4.3 (± 3.2) _ 0.2 (± 2.7)		1.5 (± 1.1)		
						Hip adduction ROM°	9.4 (± 1.7) _ 1.1 (± 3.2)		4.9 (± 2.9)		
						Hip abduction moment (Nm/kg)	0.43 (± 0.1) _ 0.24 (± 0.1)		0.40 (± 0.08)		
2) Yoo et al. (2008)	A 3D CT of the hip along with 3D gait analysis was performed to diagnose Perthes disease.	Perthes, out-toeing: 5 Perthes, in-toeing: 4 (7 boys, 2 girls)	Perthes11; range 7.0–15.3 years.	Kinematic	Pelvic and hip	At midstance phase	Out-toeing		In-toeing		Out-toeing group: Static measurement of hip rotation showed that all out-toeing patients had no or minimal limitation of external rotation but a marked decrease of hip internal rotation on the affected side compared with the unaffected side. In all out-toeing patients, affected hips were externally rotated almost throughout the gait cycle, whereas the pelvis rotated internally. At the midstance phase, the external rotation of the affected hip increased in comparison with the unaffected side, and there was an increase of internal pelvic rotation. In the sagittal plane, flexion of the affected hips decreased during gait in all out-toeing patients; hip flexion at the initial heel contact decreased compared with the unaffected side. In the coronal plane, no gait deviation was observed in terms of hip adduction and pelvic obliquity. In-toeing group: Static measurement of hip rotation revealed that external hip rotation of all in-toeing patients decreased markedly as compared with the unaffected side, whereas internal hip rotation was decreased in 3 patients. In all in-toeing patients, affected hips showed persistently increased internal rotation and external pelvic rotation during gait. At the midstance phase, internal rotation of the affected hips increased, and external pelvic rotation was compared with the unaffected side. In the sagittal plane, the hip extension was decreased during gait in 3 patients: maximal hip extension decreased compared with the unaffected side. In the coronal plane, all affected hips in in-toeing patients showed increased downward pelvic obliquity.
							Affected _ Non-affected		Affected _ Non-affected		
						Pelvic obliquity ROM	-3.3 (± 2.6) _ -4.5 (± 4.4)		-7.5 (± 3.5) _ 5.5 (± 1.9)		
						Pelvis rotation ROM°	7 (± 5.6) _ -13.8 (± 4.2)		-3.8 (± 2.9) _ 4 (± 3.9)		
						Hip flexion/extension ROM°	10 (± 7.3) _ 7.8 (± 5.9)		17.8 (± 6.8) _ 11.5 (± 6.2)		
						Hip adduction/ abduction ROM°	2.5 (± 2.9) _ 3.5 (± 2.5)		2.3 (± 3.6) _ 9 (± 2.7)		
						Hip rotation ROM°	-10 (± 0) _ 3 (± 2.5)		12.5 (± 7.7) _ 1.5 (± 0.8)		
3) Svehlik et al. (2012)	Diagnosis of Perthes disease was confirmed by X-ray.	Control: 10 Perthes, hip overloading: 8 (8 boys) Perthes, hip normloading: 19 (85% boys) Perthes, hip unloading: 13 (85% boys)	8.3 11.4 6. 5 7. 6	Temporospatial, Kinematic and Kinetic	Pelvic, hip, knee and ankle	Parameters	Overloading	Normloading	Unloading	Control	Temporospatial data: The hip normloading and hip overloading Perthes groups showed slower gait speed compared to controls, whereas the hip unloading group demonstrated faster gait speed than controls. In all Perthes groups, stride length was shorter than in the control group. Stride time was less in the hip normloading and hip unloading groups than in controls, but the hip overloading group showed increased stride time compared to controls. The cadence was higher in both hip normloading and hip unloading groups than in the control group; the cadence was lower in the hip overloading group than in controls. The stance time was slightly prolonged in all Perthes groups compared to the control group. For the overloading group, hip adduction had abnormal timing, and the hip remained longer in adduction during the stance phase of gait compared to controls. The pelvic motion was within normal limits in the sagittal and transverse planes, while in the frontal plane, the pelvis dropped towards the swinging limb. In the normloading group, the hip did not reach normal extension at the end of stance but was close to neutral in the frontal and transverse planes during single support. The pelvis revealed abnormal motion only in the frontal plane, where it was elevated on the swinging side. The unloading group walked with slight hip abduction during single support. As with the normloading group, the unloading group did not reach normal hip extension during walking. In contrast to all other groups, in this group, the hip was externally rotated during single-limb support, and an internal rotation of the pelvis was observed. The elevation of the pelvis on the swinging-limb side was even more pronounced than in the normloading group.
						Gait speed (m/s)	1.65 (± 4)	1.94 (± 3)	2.07 (± 0.26)	2.06 (± 0.3)	
						Stride length (m)	0.93 (± 0.12)	1.01 (± 0.16)	1.05 (± 0.16)	1.09 (± 0.11)	
						Stride time (s)	1.02 (± 0.45)	0.87 (± 0.07)	0.85 (± 0.12)	0.90 (± 0.12)	
						Cadence (steps/min)	130.1 (± 34.03)	138.8 (± 12.67)	144 (± 20.7)	136.62 (± 15.01)	
						Hip abduction in single stance ROM°	5.96 (± 2.03)	1.76 (± 3.6)	-1.8 (± 4.13)	3.99 (± 2.35)	
						Hip rotation in single stance ROM°	-3.54 (± 7.93)	-5.69 (± 8.21)	-12.8 (± 9.9)	-4.91(± 6.57)	
						Pelvic obliquity in single stance ROM°	2.39 (± 3.13)	-1.3 (± 3.63)	-2.22 (± 2.8)	1.5 (± 1.87)	
						Hip abductor moment in single stance (Nm/kg)	22.5 (± 3.94)	11.87 (± 2.23)	3.72 (± 4.57)	12.63 (± 3.87)	

4) Westhoff et al. (2012)	Perthes disease with unilateral involvement was diagnosed and confirmed by radiograph.	Control: 30 (14 boys, 16 girls) Perthes, total: 49 (38 boys, 11 girls) Group 1, florid stage: 36 Group 2, advanced stage: 13	Control: 8.1 (±1.2) Perthes: 7.8 (± 2.3)	Kinematic and Kinetic	Thoracic, spinal, pelvic, hip, knee and ankle	Kinematic parameters	Group 1 _ Group 2	Control	P-value 1 (Group 1 and Control)	P value 2 (Group 2 and Control)	Kinematics in the sagittal plane: The Perthes groups showed deviations mainly at the pelvis and the hip level, which were more pronounced in the florid stage (Group 1). Group 1 showed a significant increase in trunk total ROM with a significant posterior tilt position than normal. At the pelvis level, both Perthes groups showed a significant maximum pelvis anterior tilt compared to controls. At the hip joint level, Group 1 demonstrated a significant reduction in maximum hip extension on both affected and non-affected sides. ROM was significantly reduced on the involved side at the knee joint level compared to controls due to reduced maximum flexion in the swing. On the non-involved side, there was no significant deviation. At the level of the ankle, no significant difference was found. In Group 2 there were no significant differences at the level of the trunk, hip, knee or ankle compared to controls and compared to the non-involved side. Kinetics data: - Positive work: In Group 1 total work done (mainly in the hip joint) was significantly lower on the involved side than on the non-involved side compared to controls. - Negative work: Negative work done in Group 1 (mainly in the hip and knee) was also reduced compared to both the non-involved side and controls.
						Thorax ROM°	4.4 (± 2.4) _ 3.4 (± 0.9)	3.2 (± 0.9)	0.018	0.6	
						Pelvis ROM°	6.2 (± 3.2) _ 3.5 (± 2.2)	2 (± 0.8)	0.001	0.44	
							Affected _ Non-affected				
						Hip ROM° (florid stage)	33.2 (± 9.2) _ 49 (± 6.7)	44.5 (± 3.7)	0.001	0.001	
						Knee ROM° (florid stage)	50.7 (± 7.1) _ 55.7 (± 5.6)	55.7 (± 4.8)	0.001	0.329	
						Hip positive work	0.06 (± 0.03) _ 0.2 (± 0.09)	0.15 (± 0.07)	0.001	0.001	
						Hip negative work	0.1 (± 0.06) _ 0.18 (± 0.1)	0.15 (± 0.07)	0.03	0.001	
						Knee positive work	0.05 (± 0.05) _ 0.08 (± 0.06)	0.06 (± 0.07)	0.636	0.004	
						Knee negative work	0.13 (± 0.07) _ 0.18 (± 0.10)	0.18 (± 0.06)	0.014	0.001	
						Ankle positive work	0.24 (± 0.09) _ 0.27 (± 0.09)	0.28 (± 0.06)	0.052	0.019	
						Ankle negative work	0.13 (± 0.05) _ 0.12 (± 0.04)	0.13 (± 0.03)	0.558	0.023	
5) Stief et al. (2014)	Children with ipsilateral trunk lean, including children with Perthes were observed in two gait laboratories.	Control: 20 (11 boys, 9 girls) Perthes, total: 27 (19 boys, 8 girls). Group 1, natural ipsilateral trunk lean (NTL): 19 Group 2, excessive ipsilateral trunk lean (ETL): 8	Control: 9.3 (± 2.3) Perthes: 6.1 (± 1.8)	Temporospatial, Kinematic and Kinetic	Thoracic, pelvic, hip, knee and foot	Parameters	NTL group _ ETL group	Control	P-value between NTL and ETL		Temporospatial parameters: Walking speed was lower in both NTL and ETL Perthes groups than controls; however, there was no significant difference in walking speed between the Perthes groups and the control group. Kinematic data: Thorax maximum obliquity was significantly higher in the ETL group than in NTL and control groups. Pelvis maximum obliquity was lower in the ETL group than in NTL and control groups. In foot rotation, less external foot rotation was seen in the NTL group than in ETL and control groups. Kinetic data: Hip adduction moment was lower in the ETL group than in NTL and control groups. Knee adduction moment was significantly lower in the ETL group than in NTL and control groups.
						Gait speed (m/s)	0.48 (± 0.07) _ 0.44 (± 0.06)	0.49 (± 0.06)	P > 0.05		
						Thorax maximum obliquity ROM°	-4.3 (± 1.8) _ -10.3 (± 3.5)	-3.2 (± 2.2)	P < 0.001		
						Pelvis maximum obliquity ROM°	3.7(±3) _ 2.2(±3.4)	5.9 (± 2)	P > 0.05		
						Foot rotation ROM°	-2.8 (± 10.7) _ -7.3 (± 9.1)	-7 (± 5.1)	P > 0.05		
						Hip adduction moment (Nm/kg)	0.60 (± 0.12) _ 0.51 (± 0.17)	0.73 (± 0.14)	P > 0.05		
						Knee adduction moment (Nm/kg)	0.29 (± 0.14) _ 0.16(± 0.08)	0.47 (± 0.16)	P < 0.05		
6) Stief et al. (2016)	Children with the unilateral diagnosis of Perthes confirmed on X-ray.	Control: 19 (14 boys, 5 girls) Perthes: 12 (10 boys, 2 girls)	Control: 7 (± 2.5) Perthes: 5.9 (± 2)	Temporospatial, Kinematic and Kinetic	Thoracic, pelvic, hip and knee	Parameters	Perthes	Control			Temporospatial data: The Perthes group walked more slowly than controls, with shorter step lengths, but these differences were insignificant. In the frontal plane, the maximum trunk obliquity lean towards the involved side was significantly higher in the Perthes group than in the control group. Pelvis obliquity was less in the Perthes group than in controls, but this difference was not significant. In the sagittal plane, the maximum hip extension and the hip flexion/extension ROM in stance significantly decreased in the patient group. At the knee level, the Perthes group showed a significant increase in maximum knee extension and a decrease in knee flexion/extension ROM in stance compared to controls. Kinetics data: Maximum knee and hip adduction moments in terminal stance were decreased in the patient group compared to controls.
						Gait speed (m/s)	0.45 (± 0.05)	0.47 (± 0.06)			
						Step length (m)	0.81 (± 0.06)	0.84 (± 0.06)			
						At midstance phase					
						Thorax maximum obliquity°	-6.1 (± 3.2)	-1.9 (± 2.2)			
						Pelvis maximum obliquity°	3.7 (± 3.3)	4.4 (± 2.9)			
						Hip flexion/extension ROM°	33.2 (± 9.8)	46.7 (± 6)			
						Knee flexion/extension ROM°	11.8 (± 4.1)	17.3 (± 6)			
						Hip abduction moment (Nm/kg)	0.59 (± 0.18)	0.7 (± 0.13)			
						Knee abduction moment (Nm/kg)	0.26 (± 0.18)	0.37 (± 0.15)			

7) Stevens et al. (2019)	A retrospective analysis of gait data including Children with Perthes with other conditions.	Control (healthy adults): 20 Perthes: 45	Control: 22 (± 2) Perthes: 14 (± 2)	Temporospatial, Kinematic and Kinetic	Hip, knee and ankle	Parameters	Affected _ Non-affected	Control	P-value (affected side to control)	Temporospatial data: All in the Perthes group walked significantly more slowly than controls. Step length was significantly shorter on the affected Perthes side and longer on the non-affected side than controls. In the sagittal plane, the Perthes group showed a reduction in ankle plantar flexion compared to controls. Kinetic data: The total positive work was significantly reduced on the affected Perthes side compared to controls. Both hip and ankle work were significantly lower on the affected Perthes side than controls, but there was no significant difference in knee work. Ankle peak power was significantly lower in both affected and non-affected Perthes sides than in controls.
						Gait speed (m/s)	0.27 (± 0.06)	0.33 (± 0.03)	P < 0.05	
						Step length (m)	0.36 (± 0.06) _ 0.56 (± 0.1)	0.41 (± 0.03)	P < 0.05	
						Ankle plantarflexion°	13.8 (± 7.3) _ 21.6 (± 11.9)	23.5 (± 8.7)	P < 0.05	
									P < 0.05	
						Hip work (Nm/kg)	0.31 (± 0.3) _ 0.56 (± 0.22)	0.68 (± 0.18)	P < 0.05	
						Knee work (Nm/kg)	0.14 (± 0.11) _ 0.22 (± 0.16)	0.27 (± 0.1)	P > 0.05	
						Ankle work (Nm/kg)	0.66 (± 0.18) _ 0.69 (± 0.25)	0.88 (± 0.26)		
8) Karimi et al. (2019)	Children with unilateral Perthes disease classified by Mose classification based on latest follow-up X-ray.	Control: 10 Perthes: 10	Control: 8.5 (± 2.3) Perthes: 9.1 (± 2.1)	Temporospatial, Kinematic and Kinetic	Thoracic, pelvic and hip	Parameters	Perthes	Control	P-value	Temporospatial data: The Perthes group walked more slowly than controls, with significantly shorter stride length. Kinematic data: There was a significant difference between the Perthes group and controls in trunk ROM in three planes (sagittal, frontal and transverse). The Perthes group showed higher trunk ROM than controls in the sagittal and frontal planes and lower total ROM than controls in the transverse plane. Pelvis ROM was significantly increased in the sagittal plane in the Perthes group compared to controls; total pelvis obliquity and rotation were significantly reduced compared to controls. Hip ROM in the Perthes group was significantly lower in all three planes (sagittal, frontal and transverse). Kinetic data: Hip extension and adduction moment were significantly lower in the Perthes group than in the control group.
						Gait speed (m/min)	57.4 (± 6.97)	63.79 (± 8.1)	P < 0.05	
						Stride length (m)	1.06 (± 0.21)	1.23 (± 0.15)	P = 0.05	
						Cadence (steps/min)	107.6 (± 12.8)	103.5 (± 7.7)	P > 0.05	
						Thorax flexion/extension ROM°	11.12 (± 1.87)	9.43 (± 3.52)	P < 0.05	
						Thorax adduction/ abduction ROM°	14.04 (± 3.12)	12.6 (± 3.82)	P < 0.05	
						Thorax rotation ROM°	16.85 (± 1.1)	22.55 (± 3.33)	P < 0.05	
						Pelvis flexion/extension ROM°	10.26 (± 3.6)	7.83 (± 3.12)	P < 0.05	
						Pelvis adduction /abduction ROM°	8.25 (± 4.45)	10.25 (± 4.2)	P < 0.05	
						Pelvis rotation ROM°	18 (± 6.48)	21 (± 10.46)	P < 0.05	
						Hip flexion/extension ROM°	40 (± 5.6)	46.4 (± 5.6)	P < 0.05	
						Hip adduction/ abduction ROM°	13 (± 2.3)	16.9 (± 9.3)	P < 0.05	
						Hip rotation ROM°	14.7(±12.2)	23.6 (± 8.8)	P < 0.05	
						Vertical ground reaction force (N/BW)	4.8 (± 1.7)	7.6 (± 2.5)	P < 0.05	

Table 7: Frequency of Reported gait Measurement in Perthes gait Literature

		Gait Outcome	Frequency	Studies
Temporospatial Parameters		Slower Gait speed	6	Westhoff et al. (2006), Svehlik et al. (2012), Stief et al. (2014), Stief et al. (2016), Stevens et al. (2019), Karimi et al. (2019).
		Short Stride or Step length	5	Westhoff et al. (2006), Svehlik et al. (2012), Stief et al. (2016), Stevens et al. (2019), Karimi et al. (2019).
		Higher Stance phase time	2	Westhoff et al. (2006), Svehlik et al. (2012).
		Lower Cadence	1	Svehlik et al. (2012).
Kinematic Parameters	Sagittal	Increased Trunk total ROM with significant posterior tilt	2	Westhoff et al. (2012), Karimi et al. (2019).
		Increase maximum pelvis anterior tilt	2	Westhoff et al. (2012), Karimi et al. (2019).
		A significant reduction in maximum hip extension	4	Yoo et al. (2008), Westhoff et al. (2012), Stief et al. (2014), Karimi et al. (2019).
		Decreased hip flexion during the gait cycle	1	Yoo et al. (2008).
		Decrease Knee (flexion/extension) ROM	2	Westhoff et al. (2012), Stief et al. (2016).
		Decrease Ankle plantarflexion ROM	1	Stevens et al. (2019).
	Frontal	Trunk lean to the stance limb at single stance time	3	Stief et al. (2014), Stief et al. (2016), Karimi et al. (2019).
		Increase pelvic drop to the swinging limb at single stance time	6	Westhoff et al. (2006), Yoo et al. (2008), Svehlik et al. (2012), Stief et al. (2014), Stief et al. (2016), Karimi et al. (2019).
		Increased hip adduction at single stance time	3	Westhoff et al. (2006), Svehlik et al. (2012), Karimi et al. (2019).
	Transverse	Lower trunk total ROM	1	Karimi et al. (2019).
		Lower Pelvic total ROM	1	Karimi et al. (2019).
		Lower Hip total ROM	1	Karimi et al. (2019).
		Significant decrease of hip internal rotation in the out-toeing group	1	Yoo et al. (2008).
		Significant decrease of external hip rotation in the in-toeing group	1	Yoo et al. (2008).
Kinetic Parameters	Moment	Lower Hip extension moment	1	Karimi et al. (2019).
		The increased peak of Hip abductor Moment	3	Westhoff et al. (2006), Svehlik et al. (2012), Stief et al. (2014).
		Reduction peak of the Hip abductor moment	4	Westhoff et al. (2006), Stief et al. (2014), Stief et al. (2016), Karimi et al. (2019).
		Increased peak Knee abductor Moment	1	Stief et al. (2014).
		Reduction peak of Knee abductor moment	2	Stief et al. (2014), Stief et al. (2016).
	Work	Lower Hip Work	2	Westhoff et al. (2012), Stevens et al. (2019).
		Lower Knee work	1	Westhoff et al. (2012).
		Lower Ankle Work	2	Westhoff et al. (2012), Stevens et al. (2019).
	Power	Decrease peak of Ankle Power	1	Stevens et al. (2019).

3.4 Discussion

This systematic review attempted to investigate Perthes gait literature's quality and identify movement-compensation strategies during walking among non-operative children with Perthes. It identified eight papers describing gait compensation among children with Perthes disease, measured by means of marker-based motion analysis techniques. The review used four different databases (MEDLINE, CINAHL, PubMed and the Cochrane Library, using the search services Ovid, EBSCO Host and Embase of Knowledge) to provide a comprehensive overview of gait compensation literature from inception to August 2020. In this way, the chances of missing any article related to the topic were minimised.

3.4.1 Considerations when interpreting the results of the data quality assessment

The eight included biomechanical studies displayed variations in data quality, with scores ranging from 12 to 17 due to several factors. First, Yoo et al.'s (2008) study provided limited subject characteristics and measurement devices and did not include a control group. Second, The Westhoff et al. (2012) study scored poorly in the external validity, and internal validity (confounding) items as missing information on biomechanical models, type and sampling rate of measurement devices, locations of body-mounted markers and filtering and other data processing methods impede proper reproducibility. Other insufficiently reported items in Westhoff et al. (2012) were identifying the source population, the ratio between the recruited and actually participating subjects, the facilities where the measurements took place, and their staff. Finally, none of the included studies provided any information on whether a power analysis was conducted or not, and it is, therefore, questionable whether the studies had sufficient power to detect a statistically important effect.

In instrumented gait analysis, it is important to consider subject characteristics (including gender, age, body mass and height factors) because these might influence the outcome measures as this information is used to generate a biomechanical model (Sutherland et al. 1980; Cho et al. 2004). Moreover, lacking a control group may impact the interpretation of the results as the normal value did not report. Baker (2013) recommends that the researcher create normative data for each motion analysis study. Therefore, future research should encounter these issues that may affect the data quality. The recommendation for future researchers is to provide sufficient information regarding subject characteristics, measurement devices, identification of the source population, the facilities where the measurements took place, and include a control group. Derrick et al. (2020) provided a biomechanical reporting standard that could be a solution to overcome missing report biomechanical information. This biomechanical reporting standard may help understand the differences between investigations and the ability to reproduce the research. Future researchers are encouraged to report a power analysis to detect a statistically important effect and avoid the consequences of sampling error.

3.4.2 Biomechanical of gait consideration

Several biomechanical gait considerations might have negatively influenced the results and the interpretation of the data throughout the eight included biomechanical studies. The majority of the studies included reported that children with Perthes walked significantly more slowly than control group subjects, although two studies did not provide information on gait speed (Yoo et al. 2008; Westhoff et al. 2012). Yoo et al. (2008) did not consider gait speed in their study, while Westhoff et al. (2012) present no gait speed data but report no significant difference in gait speed between the Perthes group and controls; they do not indicate which of the two groups has the (non-significantly) slower walking speed. Several researchers encourage reporting gait speed in gait analysis research as speed changes gait patterns (Wagenaar and van Emmerik 1994; Van der Linden et al. 2002; Arnold et al. 2007). Therefore, to identify deviations in the kinematic and kinetic data, matching the gait speed of the control group subjects to that of the patient group is highly important in order to avoid misinterpretations of deviations that are solely due to gait speed. Schwartz et al. (2008) investigated the effect of a wide variety of walking speeds on the gait of 83 typically developing children. They found that speed significantly influences temporal-spatial, kinematic and kinetic parameters. On the other hand, it has to be taken into account that a reduced gait speed might already be considered a compensatory strategy. Therefore, gait speed should be reported in all gait studies as an essential outcome related to kinematic and kinetic parameters.

Another factor that is known to influence gait patterns is footwear. Four studies in this review (Yoo et al. 2008; Svehlik et al. 2012; Karimi et al. 2019; Stevens et al. 2019) did not provide any information on the footwear of the subjects; this is another weak point in those studies. Murley et al. (2009) and Radzimski et al. (2012) conducted a systematic review to evaluate the effect of footwear on muscle activation in the lower limb and influence the kinetic parameters. Murley et al. (2009) evaluated 20 studies investigating the effect of footwear on lower limb muscle activity during walking by using an electromyography tool. They found that footwear alters lower limb muscle activation. Moreover, Radzimski et al. (2012) evaluated 33 studies examining footwear modification as a conservative intervention to decrease the peak of external knee adduction moment and pain associated with knee pain. The result of Radzimski et al. (2012) found that footwear with lateral wedging was associated with the decreased peak of external knee adduction moment in both healthy subjects and individuals with osteoarthritis. In addition, this study found that subjects who wear their shoes were more likely to increase the peak of external knee adduction moment than barefoot walking in healthy subjects. Therefore, barefoot walking is highly recommended for gait studies to eliminate the influence of footwear on gait analysis.

The often-missing evaluation of the unaffected side in patients with unilateral pathologies is another weak point of the reviewed papers. Given that the three studies that investigated both sides (Yoo et al. 2008; Westhoff et al. 2012; Stevens et al. 2019) found compensations on the unaffected side, the studies that evaluated only the affected side potentially missed compensatory mechanisms occurring in the other limb.

Evaluating more lower limb joints is also important to understand the nature of Perthes disease in walking parameters. The hip and pelvic joints were most considered in the Perthes walking literature, included in eight and six studies. The trunk and knee were considered by five studies, while the ankle joint was considered least in the Perthes walking literature, being included in only four studies. Based on the biomechanical of gait consideration section, future research is recommended to report gait speed, consider barefoot walking, evaluate non-affected side, and evaluate lower limb joints to understand Perthes disease's effect better.

3.4.3 Identification and interpretation of compensatory movement

3.4.3.1 Temporospatial outcome measures

Perthes groups demonstrated slower gait speed (Westhoff et al. 2006; Svehlik et al. 2012; Stief et al. 2014; Stief et al. 2016; Stevens et al. 2019; Karimi et al. 2019), with short stride length (Westhoff et al. 2006; Svehlik et al. 2012; Stief et al. 2016; Stevens et al. 2019; Karimi et al. 2019), and prolonged stance phase time on the affected Perthes side compared to controls (Westhoff et al. 2006; Svehlik et al. 2012). This mechanism of lowering gait speed and prolonging standing time during the stance phase might be because the children feel unsafe; Hailer et al. (2012) found that joint instability is responsible for a high incident rate of fracture and joint dislocation in Perthes subjects. In addition, Karimi and Esrafilian (2013) found that children with Perthes demonstrated postural instability due to hip muscles weakness. These findings suggest that gait stability might be affected in this group of patients. Van der Krogt et al. (2014) investigated gait in 11 typically developing children and nine children with cerebral palsy under three different walking conditions: walking on a treadmill with a virtual environment, overground walking in a gait analysis lab, and walking in a natural environment outside the gait analysis lab. They found a link between reduced gait speed, short strides (length and width) and gait instability among children with cerebral palsy. As no Perthes literature considers the stride width parameter, gait stability is still unclear in this group of patients. Thus, it is important to further investigate gait stability and its link with falling risk and prevention of injuries such as fractures (Lin et al. 2015; Tracy et al. 2019).

3.4.3.2 Kinematic outcome measures

The literature describes movement-compensation with regard to three different planes, sagittal, frontal and transverse, considering the trunk, spine, pelvis, hip, knee and ankle. First, different patterns were seen in the sagittal plane based on Perthes disease severity (Westhoff et al. 2012). In the florid stage, children with Perthes demonstrated a flexion pattern in lower limb joints. Trunk movement showed a significant increase in total ROM. Relative to the pelvis, the trunk was in a significantly more pronounced posterior tilt position (‘‘spine tilt’’) compared to normal, while the movement and position of the trunk relative to the global coordinate system (‘‘thorax tilt’’) remained physiologic. At the pelvis level, maximum anterior tilt was significantly increased in both florid and advanced groups compared to normal. Minimum anterior tilt and total ROM were also increased, and there were significant differences at the hip joint level of both sides; on the involved side, total hip ROM was severely reduced compared to normal. It was related to reduced maximum hip extension; maximum hip flexion was normal. On the non-involved side, total hip ROM was increased compared to normal and to the involved side due to an increase in maximum hip flexion. ROM was significantly reduced on the involved side at the knee joint level compared to normal due to reduced maximum knee flexion in the swing. On the non-involved side, there were no significant deviations. At the ankle level, no significant differences were found, but the Perthes group demonstrated a reduction in ankle plantarflexion compared to controls. In the advanced stage, there were no significant differences at the trunk, hip, knee or ankle level compared to controls and the non-involved side. This flexion compensation pattern has been reported as a protective mechanism of the affected joint to reduce joint pain. Frigo et al. (1996) found that patients with juvenile chronic arthritis presented hip flexion with less knee extension, especially at the late stance phase, to reduce pain and protect the joint.

Second, two distinct gait patterns were seen in the frontal plane, both deviating from normal. The first is the Trendelenburg pattern, characterised by pelvic drop towards the swing limb and increased hip adduction with trunk lean to the stance limb in relation to the pelvis. The second is the Duchene pattern, characterised by trunk lean towards the affected stance limb, with pelvis lifting, hip abduction and external rotation in the stance phase of the gait. Trunk leaning is a notable sign of movement-compensation among children with Perthes. This can be split into natural ipsilateral trunk lean (NTL) and excessive trunk lean (ETL). Thorax maximum obliquity was significantly increased in the Perthes groups, especially in the ETL group, compared to the control group. Pelvis maximum obliquity was decreased in the Perthes groups compared to controls, but this difference was not significant. These deviations in the frontal plane may be due to hip and knee flexion during walking (as presented in the sagittal plane) and weakness in the hip abductor muscle. Krautwurst et al. (2013) support the role of the abductor's muscle to stabilise the pelvis in the frontal plane in cerebral palsy patients who demonstrated the Trendelenburg gait pattern. They found that hip abductor muscle weakness in children with cerebral palsy was associated with lower hip abductor moment and increased trunk lean to the ipsilateral side, while the pelvis remained stable as a compensation mechanism.

Third, in the transverse plane, two distinct foot patterns, out-toeing and in-toeing, were visible. In all out-toeing patients, affected hips were externally rotated almost throughout the gait cycle, whereas the pelvis rotated internally. At the midstance phase, the external rotation of the affected hip increased compared with the unaffected side, and internal pelvic rotation also increased. In all in-toeing patients, affected hips showed persistently increased internal rotation and external pelvic rotation during gait. At the midstance phase, internal rotation of the affected hip and external pelvic rotation increased compared with the unaffected side. Children with Perthes presented gait compensation in the transverse plane to avoid the femoral hump deviation impinging against the anterior acetabular rim during full flexion movement in the hip joint.

Another classification for children with Perthes was identified by Svehlik et al. (2012). They divided children with Perthes into three sub-groups (overloading, normloading and unloading) based on hip joint loading. The hip joint loading was formed according to the extent of the time base integral of the hip abductor moments during the single-limb stance on the affected side in the frontal plane. First, the hip was in the extension position at the end of the stance in the overloading group and did not differ from the normal group. However, although mean hip adduction during single support was not different from that of the control group, its timing was abnormal, and the hip remained longer in adduction during the stance phase of gait. There was no rotational pathology of the hip in the overloading group. Pelvis motion was within normal limits in the sagittal and transversal planes. The pelvis dropped towards the swinging limb in the frontal plane and was not compensated for by the abductor's muscles (as observed in normal gait). Second, the normloading group showed normal time-distance parameters except for prolonged stance duration. The hip did not reach normal extension at the end of stance but was close to neutral in the frontal and transversal planes during single support. The pelvis revealed abnormal motion only in the frontal plane, where pelvis elevation on the swinging side was observed. Third, the unloading group walked with slight hip abduction during single support. Similar to the normloading group, the unloading group did not reach normal hip extension during walking. In the unloading group, in contrast to all other groups, the hip was externally rotated during single support, and an internal rotation of the pelvis was documented. The elevation of the pelvis on the swinging-limb side was even more pronounced than in the normloading group.

3.4.3.3 Kinetic parameters

It is clear from Svehlik et al. (2012) study that hip abductor moment is an important outcome measure to determine loading in the hip joint. In Westhoff et al.'s (2006) study, the Trendelenburg group showed increased hip abductor moment compared to the control group, while the Duchene group demonstrated statistically significantly reduced abductor moment during the single-limb stance phase. In addition, Svehlik et al. (2012) found that the overloading group demonstrated higher hip abductor moment than the normloading group and the control group, while the unloading group displayed reduced hip abductor moment during the stance phase. Trunk leaning may be another factor that influences hip joint loading. Stief et al. (2014) and Stief et al. (2016) found that hip adduction moment was lower in children with Perthes with ETL than those with NTL and controls, but these differences were not significant.

Another important kinetic factor is hip joint work. Westhoff et al. (2012) and Stevens et al. (2019) found that, in the florid stage, positive work in the hip joint was significantly lower on the involved side than on the non-involved side and in controls. Negative work was also reduced on the affected side compared to both the non-affected side and controls. This lower level of work done is an indicator of reduced activity of the hip muscles on the involved side and can be interpreted as an alleviation mechanism to reduce pain (Westhoff et al. 2012). However, there is little work on knee and ankle joints. Only four out of the eight articles considered the knee joint, and one article considered the ankle joint. The kinetic parameters for knee joints revealed that knee adduction moment might be affected by trunk leaning pattern, as described in Stief et al. (2014) and Stief et al. (2016). These works found that knee adduction moment was significantly lower in Perthes groups with trunk leaning, especially those with ETL, compared to controls. This altered gait pattern may increase the lever arm around the knee joint by shifting the GRF to the knee joint centre laterally. This lateral adjustment is argued to increase lateral tibiofemoral compartment load (Sharma et al. 2000), which could be sufficient to deform the lateral compartment of the knee or influence the remaining growth plate and the physiological development of the mechanical axis of the leg in young patients and may lead to the development of knee osteoarthritis. Williams et al. (1993) investigated the late knee problems in myelomeningocele (spina bifida) patients. They assessed the incidence and aetiology of knee problems in a long-term follow-up of myelomeningocele patients. Seventeen patients with myelomeningocele out of 72 community ambulators had significant knee symptoms. They found that patients with myelomeningocele have a characteristic gait, which presented abnormal stress on the knee, leading to medial and anteromedial rotary instability and eventual degenerative change.

The kinetics of the ankle joint are given little attention in the literature on children with Perthes. Stevens et al. (2019) is the only study considering the kinetics of the ankle joint. That study found that children with Perthes demonstrated significantly lower ankle work and power in both affected and non-affected sides than controls; this was more pronounced on the affected side.

3.4.3.4 Summary of compensatory mechanisms

Children with Perthes walked with obvious Trendelenburg’s sign, including pelvic drop to the swing limb with hip slightly adducted in the single stance phase due to hip abductor muscle weakness. This weakness in hip abductor muscle is related to increased hip abductor moment as the hip abductor muscle produces insufficient power to encounter the great GRF responsible for increased hip loading. Therefore, children with Perthes use a variety of strategies to reduce hip loading – reducing gait speed, shortening stride length, prolonging stride time, and decreasing the work around the hip joint. Gait speed is an important parameter that may influence temporospatial, kinematic, and kinetic parameters, as found in several studies (Silverman et al. 2008; Van Hamme et al. 2015; Begue et al. 2018; Fukuchi et al. 2019; Oudenhoven et al. 2019). Therefore, if children change the gait speed parameter, the kinematic and kinetic parameters may also change. Although children with Perthes slowed their gait speed and reduced work in the hip, their hip joint loading was still higher than that of controls. It may relate to other factors such as the abnormal shape of the hip joint and degree of muscle weakness. More research on Perthes movement-compensation during walking, including evaluating gait stability, is needed to help in setting goals for rehabilitation management.

3.5 Clinical implications

Children with Perthes demonstrated compensation strategies in all three planes, including many joints, to alleviate pain, encounter hip muscle weakness and decrease the effect of abnormal shape of the femur head. Most movement-compensation identified in this review was in the pelvis and hip during single stance time in the frontal plane. This compensation in the frontal plane affected temporospatial, kinematic and kinetic parameters. Children with Perthes displayed slower gait speed, shorter stride length and prolonged stance time. In addition, the hip presented in the adduction position with the pelvis dropped towards the swing limb in the single-limb stance phase. This compensatory movement in the hip and pelvis increased the load in the hip joint as the hip abductor moment increased. Therefore, treatment planning should include a careful evaluation of the pathologic gait pattern by motion analysis techniques, with particular attention to possible compensatory mechanisms in the trunk and other lower limb joints and sound limbs. For the planning of physical therapy management, focusing on strengthening the hip abductor muscle is highly important to stabilise the pelvis and decrease the hip abductor moment in the affected Perthes hip. Hip loading was higher in Trendelenburg gait than Duchene gait as the hip abductor moment was high. A relationship has been found between higher hip abductor moment and decreased hip abductor muscle strength (Westhoff et al. 2006). Plasschaert et al. (2006) investigate the relation of the weakness of the hip abductor muscle to poor clinical results in patients with Perthes disease. They reported that patients with Perthes disease who demonstrated weakness in hip abductor muscle had increased net adduction moment and developed gait compensation-movement. Horsak et al. (2019) conducted a randomised controlled trial to investigate the potential effect of an exercise programme, including hip abductor and knee extensor strength, in improving gait function among 19 children with obesity. They found that the exercise programme was able to increase muscular strength, especially in the hip abductors. Moreover, the children in the exercise programme walked with less maximum hip adduction and reduced pelvic drop during the single stance phase. Therefore, strengthening the hip abductor muscle could enhance children's walking with Perthes and prevent lower limb compensation. In the case of joint disease, patients could even be instructed in proper compensatory strategies to promote locomotion. Regular physical therapy consultations and preventive treatment methods (e.g. specific exercise therapies) could prevent further deterioration, such as the degeneration of cartilage tissue due to misuse of the joints (osteoarthritis) (Alghamdi et al. 2004).

3.6 Research implications

The sparse amount of available evidence addressing the identification of compensatory mechanisms during pathologic gait and the (in part) rather low methodological quality suggest that more research has to be conducted in this area. Enhanced research on evaluating gait stability is needed to provide complete information about gait compensation in children with Perthes. The unaffected side should always be included in evaluating patients with unilateral pathology to ensure that secondary deviations are understood in a more comprehensive context. Finally, researchers should focus on higher methodological quality, better-controlling factors such as gait velocity and footwear and considering lower limb kinetic parameters. Therefore, the second study in this current study will investigate the gait stability, considering stride width, evaluating both affected and non-affected sides of patients with Perthes. In this way, it is intended to overcome the identified gap in Perthes literature and might help clinical providers understand Perthes disease's nature.

3.7 Conclusion

It is difficult to draw a firm conclusion about non-operative Perthes disease because the literature uses different classifications of the condition. Some studies divided children with Perthes according to hip loading, while others divided them based on the severity of the disease. However, the previous literature provides evidence that these groups of patients are suffering from Perthes disease and may influence their walking, affecting the trunk and lower limbs joints and the sound limb. Children with Perthes disease showed signs of gait instability as they walked more slowly than control groups and spent a relatively prolonged time in the stance phase to avoid standing on one leg. As no literature considers gait stability in children with Perthes, future work is needed. The previous literature contains certain limitations that may affect the quality of evidence. All the previous studies fail to mention the power calculation, which may affect internal validity, and the study setting, which might affect external validity. Despite gait abnormality in children with Perthes being biomechanically considered in the previous literature, little attention has been given to kinetic parameters, especially for knee and ankle joints. Kinetic parameters, especially knee adduction moment, are reported as providing important signs to predict knee degeneration and develop a suitable therapeutic intervention, as suggested in Foroughi et al.’s (2009) systematic review. Of the previous literature, Westhoff et al. (2006), Svehlik et al. (2012), and Westhoff et al. (2012) recommend performing ipsilateral trunk lean towards the involved side as an unloading mechanism to reduce the load in the involved hip joint. This recommendation may be made because the above researchers considered only the hip joint and paid less attention to knee joints, especially knee adduction moment. Stief et al. (2014) and Stief et al. (2016) considered knee adduction moment to evaluate the effect of ipsilateral trunk lean on knee joints. They found that the effect of ipsilateral trunk lean was pronounced in the knee joint and could initiate degenerative changes in knee cartilage. They suggested that ipsilateral trunk lean should not be recommended as an unloading mechanism for the hip joint in isolation but that its potential to cause excess lateral knee joint loading should be considered. Thus, in future research, considering all lower limb joints with full biomechanical data may help to provide an appropriate recommendation.

Chapter Four: Methods

4.1 Overview

This chapter describes the methods used in this thesis that was divided into two main sections. The first section covered the biomechanical method for functional activities, while the second section covered the questionnaires method for physical activity level, quality of life and management of physiotherapy treatment. As explained earlier, this doctoral thesis sought to explore compensation-movement during walking, single leg balance and squat activities, physical activity level, quality of life and management of physiotherapy treatment among non-operative children with Perthes disease. Two groups were recruited to conduct this study: typically developing children (n=15) and non-operative children with Perthes disease (n=9).

4.2 Study design

An observational, case-control study design was used. The method employed was twofold. The first technique explored differences in three functional activities (walking, single-leg balance and squat), evaluated using a 3D motion analysis system (Vicon, Oxford Metrics Ltd., Oxford, UK). The second used questionnaires as tools to explore physical activity level and quality of life and how non-operative children with Perthes and their families manage physiotherapy treatment. The data for functional activities, physical activity level and quality of life were compared between non-operative children with Perthes and matched typically developing children (control group). This study design is commonly used to compare patients who have a disease or outcome of interest ("cases") with a group who do not have the condition but are otherwise similar ("controls") (Rose and Barker 1978). Moreover, it allows for potential confounding factors to be controlled by measuring them and making appropriate adjustments in the analysis (Rose and Barker 1978). In this study, age, height, sex and body mass were identified as potential confounding variables. These two aspects of the method may help physiotherapists establish good rehabilitation goal setting based on a movement analysis approach and patient/parent beliefs.

4.3 Ethical considerations

Ethical approval for the study was obtained from the School of Healthcare Sciences Research Ethics Committee (9 January 2019) (appendix xv). All photographs involving human subjects included in this thesis are reproduced with the written permission of the subjects.

4.3.1 Data collection

Full informed consent and assent were achieved on the arrival of children and parents at the trial session. The researcher explained the study protocol to the participants in detail, with children given the opportunity to ask questions. Subsequently, each participant completed and signed a consent and assent form (appendix vii and viii) and was informed of their right to withdraw from the study at any time. Subjects were asked to wear swimsuits throughout the trial session. Changing facilities and privacy curtains were provided, and the laboratory door was closed to prevent disruption during data collection. Palpation of bony anatomical landmarks (including the spine and pelvis) was required to affix the reflective markers accurately. Full informed verbal consent was always gained before palpation to ensure that the subject felt comfortable.

4.3.2 Data storage and handling

All participants' identifiable electronic data was stored on a password-protected encrypted hard drive. Permission-to-contact forms and written information collected at the data collection session (e.g. demographics and questionnaires) were stored in a locked filing cupboard in a secure room within the university accessible only by the researcher. Anonymised codes for all subjects were used throughout, with the database linking session codes with specific subjects stored on encrypted password-protected devices to ensure children were non-identifiable.

4.3.3 Dissemination

The intellectual property rights of this research are held by Cardiff University. The study results will be published in a peer-reviewed journal, and all parents will be informed of the journal reference upon publication.

4.3.4 Risk assessment

A full risk assessment (Cardiff University: http://www.cardiff.ac.uk/osheu/toolkit/raindex.html) was conducted prior to data collection (appendix xiv). All children were informed of their right to decline to complete (or continue with) any activity that they felt increased their discomfort beyond a reasonable level. One potential risk for this study was slips and falls; action was taken to reduce this risk, including acceptable lighting and a dry floor being ensured prior to conducting any investigation. A second potential risk was that of tripping over wires or cables on the floor of the gait laboratory; the preventive action taken was to reduce the number of wires to a minimum and to move those remaining out of the way. Visitors were warned of their presence when entering the laboratory. The last potential risk was that of allergic reaction to the reflective markers, and this was resolved by ensuring that each child was asked about allergies before data collection. No adverse effects or hazards were observed on the completion of the study.

4.3.5 Recruitment

A) Control subjects

Typically developing children were recruited as a “control group” via word of mouth and the Cardiff University advertisement board and friends and relatives of staff whose children met the inclusion criteria (Table 8). Interested parents contacted the researcher via information in flyers and invitation letters (appendices ix, xiv and xvii). The researcher checked the eligibility criteria for the control group before sending the information sheet via mobile phone (appendices iii, iv and xviii).

B) Perthes subjects

The non-operative Perthes group was recruited through the Perthes Association charity: a recruitment advertisement was placed on the charity website and Facebook page (appendix xvi). The researcher telephoned all subjects who asked to be contacted to explain the study in greater detail, answer any queries and conduct a series of screening questions to establish whether the children with Perthes met the inclusion/exclusion criteria (Table 8). Interested parents and children in both groups received the information sheet and dates for the project via email, with appointment notices sent 72 hours before the trial day.

4.3.6 Eligibility criteria

On the day of the trial, the eligibility criteria (see Table 8) were re-checked with the children’s parents before signing consent forms (appendices vii and viii). The researcher described the procedure and the aims of the study to parents and children. The control group came in for two sessions to establish the quality of biomechanical movement data. The control group attended two sessions, while the Perthes group attended one session due to limited funding and the majority of the Perthes group were outside Cardiff city.

Strict inclusion and exclusion criteria were applied to both control and Perthes groups, based on the literature. Inclusion criteria for the control group included ages between 6 and 12 years to act as age-matched controls for the Perthes group. History of surgery to lower limb and abnormal walking pattern were classed as exclusion criteria (Westhoff 2006; Stief 2014; Stief 2016). All children underwent a physical examination before instrumented movement analysis to ensure that each control subject met the eligibility criteria (Table 8).

Table 8: Eligibility criteria

	Control group	Perthes group
Inclusion criteria	- Aged between 6 and 12 years - Any gender - Free from any disease condition - Able to walk without an assistive device	- Aged between 6- and 12 years - Any gender - Unilateral Perthes with mild or moderate involvement - Free from any pathologies (other than Perthes on one side) - Able to walk without an assistive device
Exclusion criteria	- Previous surgery to lower extremities - Disorders leading to gait deviations	- History of fractures - Previous surgery on the affected or sound limb - Musculoskeletal injury of the lower limbs - Neurological pathologies

The Perthes group inclusion criteria included a diagnosis of Perthes disease, and a minimum age of 6 years and a maximum age of 12 years. Patients were excluded if they had a history of previous lower extremity surgery or disorders affecting gait other than Perthes on one side. Exclusion criteria also included walking with assistive devices (e.g. orthosis or crutches) (Westhoff et al. 2006; Stief et al. 2014; Stief et al. 2016). Before starting the trial, all children underwent a routine physical examination. The physical examination was based on the Conservative Management of Legg-Calve-Perthes Disease guidelines (2011). It is recommended that the Classification Instrument in Perthes (CLIPer) be used to place the patient into a rehabilitation classification phase upon examination (appendix xviii). Several orthopaedic classification systems have been used to determine the stage and severity of the disease based on radiographic findings (Villet and Laville 2003; Herring et al. 2004; Stepanovich et al. 2017).

In contrast, the CLIPer is a functional classification scale developed by the authors of the Conservative Management of Legg-Calve-Perthes Disease guideline (2011). It is based on physical impairments (pain, range of movement, strength, balance and gait) and guides rehabilitation progression. Although there is no published research on the validity and reliability of the CLIPer tool to date, it was used because it would have been challenging to obtain radiographic data to classify the patients with Perthes in this study as the recruitment process was conducted through the Perthes Association charity. The CLIPer checklist was used to identify the level of impairment. It has 24 scores, and the stage of rehabilitation is based on the total score. If a Perthes child has a total score of 14 to 24, that is considered severe impairment; a total score of 6 to 13 is considered a moderate impairment, while a total score of 0 to 5 is considered a mild impairment. Therefore, using the CLIPer classification helped the researcher identify the impairment levels among the Perthes group on the day of the trial.

4.3.7 Location

The control group and children with Perthes were invited to the Research Centre for Clinical Kinesiology (RCCK) at the School of Healthcare Science, Cardiff University, Wales, UK.

4.3.8 Sample size

A sample size calculation was performed using the G-power software, to estimate the number of participants required to answer the research question. The primary outcome in this study was hip abductor moment based on Stief et al.(2014) study, which examined gait compensation-movement in the frontal plane among children with Perthes disease. Their data showed mean (±SD) hip abductor moment for children with Perthes disease was 0.60 (±0.12) Nm/kg and for typically developing children 0.73 (±0.14) Nm/kg. With $\alpha = 0.05$ and a power of 0.8 based on a two-tailed test, the required minimum sample size for the study is n=17 in each group. However, this study included fifteen typically developing children (control) and nine non-operative children with Perthes as a convenience sample. A convenience sample was used for three reasons. First, Perthes disease is considered rare, affecting 5.7 in 100,000 born in the UK (Perry et al. 2012). Second, the researcher had a time constraint for completing the PhD and an arrangement was made to book the RCCK lab. Dealing with children is a challenge, and the researcher had to find a suitable time for parents and children when the RCCK lab could be booked. Third, five control subjects and three Children with Perthes were not able to participate because of the impact of COVID-19. The UK government took action to stop travel and introduce a lockdown to limit the coronavirus outbreak. In this situation, it was useful to conduct the study with a convenience sample, as Etikan (2016) stated. However, the numbers of participants in this thesis (15 controls and 9 non-operative children with Perthes) are similar to those reported in the literature on gait movement among patients with Perthes (Yoo et al. 2008; Stief et al. 2016; Karimy et al. 2019).

4.3.9 Clinical Examination

All tests took place for both groups at the Research Centre for Clinical Kinesiology (RCCK), School of Healthcare Sciences, Cardiff University, Wales, UK. Each session lasted for approximately 60 to 90 minutes. For every child examined in the laboratory, the researcher performed a comprehensive clinical examination before data collection. It included demographics and anthropometric data, assessment of joint ROM measured by a manual goniometer, muscle strength measured by a handheld dynamometer (HHD), and pain level measured by the Wong-Baker scale. All these measurement tools have a reliable and valid value in the paediatric population (McGrath 1989; Sabharwal and Kumar 2008; Garra et al. 2010; Nussbaumer et al. 2010; Hébert et al. 2011). This information will be used during data interpretation to help determine the potential causes of movement abnormalities. The following section highlights the protocol for collecting the demographics and anthropometric data, joint ROM, muscle strength and pain level.

4.3.9.1 Demographics and anthropometrics

Each child's date of birth and gender were reported on the data collection sheet. Height and mass were measured for each child to acquire a body mass index (BMI) score. Mass was recorded using digital floor weighing scales (Seca 888, Seca Ltd., Medical Scales, Birmingham, UK). Height was recorded using a mechanical telescopic measuring rod (Marsden HM-250P Leicester Portable Height Measure). Children were instructed to take off their shoes and socks for height and weight measurements. Additionally, lower limb length (anterior superior iliac spine [ASIS] to medial malleolus) and knee and ankle width were measured bilaterally using a tape measure, as described in the Bodybuilder model (Vicon Nexus guideline) (Figure 5).

Figure 5: Anthropometric measurements

4.3.9.2 Range of motion

Figure 6: Manual goniometer

The manual goniometer showed good validity and reliability. Nussbaumer et al. (2010) investigated the validity and reliability of manual goniometers to measure the passive hip range of motion (ROM) in femoroacetabular impingement patients and controls. In two trial sessions, they evaluated passive hip flexion, abduction, adduction, and internal and external rotation ROM using a conventional goniometer and an electromagnetic tracking system (ETS). A total of 15 patients and controls of the same sex and age participated in this study. The finding was that the goniometer showed greater hip ROM values than the ETS (range: 2.0–18.9 degrees, $p<0.001$); good concurrent validity was only observed in hip abduction and internal rotation, with ICCs of 0.94 and 0.88, respectively. Both devices recorded lower hip abduction ROM in patients than in the control group ($p<0.01$). Test-retest reliability showed promising results, with ICCs higher than 0.90, except for hip adduction (0.82–0.84). There was no significant difference in reliability between the goniometer and the ETS. Nussbaumer et al. (2010) suggest that conventional manual goniometers can be used confidently for longitudinal assessments in the clinic. Therefore, a simple long-arm goniometer (Idass Goniometer, Launceston, UK) with a 360-degree scale marked in one-degree increments was used in this project to test ROM of lower extremities in the Perthes and control groups (Figure 6). The protocol for measuring lower extremity ROM is illustrated in the following table based on Fox and Day's (2009) protocol (Table 9).

Table 9: Goniometer protocol

	Extremity position	Goniometer axis	Goniometer: stationary arm	Goniometer: movable arm	End position	Comment
Hip flexion	The subject is in the supine position on the plinth. Their hip is in neutral, and the knee is in extension.	Placed over the greater trochanter of the femur.	Parallel to the mid-axillary line of the trunk.	Parallel to the longitudinal axis of the femur, pointing towards the lateral epicondyle of the femur.	The hip is flexed to the limit of motion.	Compensation can be made by flexion of the lumbar spine.
Hip extension	The subject lies prone in anatomical position on a firm, flat surface. The subject should maintain contact of both iliac crests with the surface during measurement.	Placed over the greater trochanter of the femur.	Parallel to the mid-axillary line of the trunk.	Parallel to the longitudinal axis of the femur, pointing towards the lateral epicondyle of the femur.	The hip is extended to the limit of motion.	Compensation can be made by extension of the lumbar spine.
Hip abduction	The subject is in the supine position on the plinth.	Placed over the anterior superior iliac spine (ASIS) of the innominate bone, on the side of the hip being measured.	Placed along a line between the two ASISs.	Parallel to the longitudinal axis of the femur.	Hip abducted to limit of motion.	The pelvis can be stabilised by fixing opposite leg slightly abducted and flexed over edge of plinth.
Hip adduction	The subject is in the supine position on the plinth. Their hip is in neutral, and their knee is in extension.	Placed over the ASIS.	Placed along a line between the two ASISs.	Parallel to the longitudinal axis of the femur.	The hip is adducted to the limit of motion.	The opposite leg is abducted over the side of the plinth and the foot is resting on a stool.
Hip rotation	The subject is in the sitting position on a raised plinth. Their hip is in 90° of flexion and neutral rotation, with the knee flexed to 90°. The opposite hip is abducted, and the foot is supported on a stool.	Placed over the mid-point of the patella.	Perpendicular to the floor.	Parallel to the longitudinal axis of the tibia.	External or internal rotation to the limit of motion just before the pelvis starts to lift from the plinth.	
Knee flexion	The subject is in the supine position on the plinth.	Placed over the lateral epicondyle of the femur.	Parallel to the longitudinal axis of the femur.	Parallel to the longitudinal axis of the fibula.	The hip and knee are flexed to the limit of motion.	
Knee extension	The subject is supine with extended hips and knees.	Placed over the lateral epicondyle of the femur.	Parallel to the femur and trochanter major.	Parallel to tibia and the lateral malleolus.	The knee is extended to the limit of motion.	Extension deficit is reported with a minus.
Ankle dorsi/ plantar flexion	The subject is in supine position. The knee is extended.	Placed below the lateral malleolus of the fibula.	Parallel to the longitudinal axis of the fibula.	Parallel to the longitudinal axis of the fifth metatarsal.	The foot is dorsiflexed or plantarflexed to the limit of motion.	Hindfoot is maintained in neutral to avoid calcaneal add/abduction

4.3.9.3 Muscle test

Figure 7: MicroFET hand-held dynamometer

Muscle strength is an essential clinical measure in paediatric rehabilitation. Limitations in walking and rising to stand, for example, are related to muscle strength in several different clinical groups (Kordi et al. 2016). Moreover, physical capacity as measured using standardised clinical tests has been shown to improve with improvements in muscle strength (Hébert et al. 2015). Since children with physical disabilities often have bilateral impairments, a comparison muscle group “outside of the person” may be necessary to predict muscle weakness. It implies the use of reference data in the absence of true normative values. Since muscle strength increases with growth and maturation, this type of information may also provide data on the extent of, or changes in, strength impairment that cannot be predicted by simply comparing strength results for the same individual over time. For reference values to be useful in clinical decision-making, however, they need to be obtained using clinically feasible methods and yield valid and reliable data, such as hand-held dynamometry.

Wessel et al. (1999) evaluated the reliability of strength testing in children with juvenile arthritis (JA) and studied the relationship between strength and function. This study included 53 children with JA who were measured for grip and pinch strength. Isometric forces generated by hip abductors and knee extensors were measured by an HHD for 29 children. Two physiotherapists each conducted each of the tests twice to detect intra-rater and inter-rater reliability. Reliability was examined with ICCs. The relationships of strength and function were detected by Pearson and Spearman correlations. The results show that all measures displayed good intra-rater (ICC: 0.92–0.97) and inter-rater (ICC: 0.80–0.95) reliability. The authors conclude that isometric strength in children with arthritis can be reliably measured in a clinical setting.

Hébert et al. (2011) evaluated feasibility, reliability, SEM and concurrent validity for maximal isometric torque (MIT) using a specific HHD protocol. Using an HHD, the MITs of selected upper and lower limb muscle groups were examined in 74 children aged between 4 and 17 years. The results demonstrated that the mean intra- and inter-rater reliability (ICC) varied from 0.75 to 0.98, except for ankle dorsiflexor inter-rater reliability (mean ICC: 0.67). The SEM ranged from 0.5 to 4.9 Nm and was highest for hip extensors. Mean concurrent validity (ICC) ranged from 0.78 to 0.93, except for ankle plantar flexors (mean ICC: 0.48). The authors concluded that the HHD protocol was valid and reliable over a wide age range among children and could be used in clinical settings.

To measure isometric muscle strength using an HHD, Hébert et al. (2015) designed a protocol to measure lower extremity muscles. The standardised positions and HHD placement for each muscle group tested are described in detail in the following table. This protocol is valid and reliable (Hébert et al. 2015) (Table 10). The MicroFET wireless HHD was used in this study (Figure 7).

Table 10: Hand-held dynamometer protocol

Muscle group	Participant's position	Limb/joint positions	HHD placement
Hip flexors	Supine	Hip and knee flexed to 90°, leg supported on a stool on the table.	The strap used, attached at one end to HHD hook attachment and the other end around the anterior surface of the thigh, most distal, just proximal to knee fold.
Hip extensors		Hip and knee flexed to 90°, leg supported on a stool on the table.	The strap used, attached at one end to HHD hook attachment and at the other end around the posterior surface of the thigh, most distal, just proximal to the popliteal fold.
Hip abductors		Hip and knee flexed to 90°, contralateral limb stabilised with a strap around the distal thigh and attached to the table.	Most distal on the lateral surface of the thigh, on the lateral epicondyle of the knee.
Hip adductors		Hip and knee at 0°, contralateral limb stabilised with a strap around the distal thigh and attached to the table.	Most distal on the medial surface of the thigh, on the medial epicondyle of the knee.
Knee flexors	Sitting	Knee flexed to 90°, hip flexed to 90°, trunk straight.	Most distal on posterior surface of leg, just proximal to ankle.
Knee extensors		Knee flexed to 90°, hip flexed to 90°, trunk straight.	On the anterior surface of the leg, just proximal to the ankle, HHD surface inserted between the strap (around the anterior surface of the leg and the table leg) and the subject's leg, 5 cm above the lateral malleolus.
Ankle dorsiflexors	Supine	Hip and knee flexed to 90°, leg supported on a stool on the table, ankle flexed to 90°, foot off the table edge.	Just proximal to metatarsophalangeal joints on the dorsal surface of the foot.
Ankle plantarflexors		Hip and knee flexed to 90°, leg supported on a stool on the table, ankle flexed to 90°, foot off the table edge.	Just proximal to metatarsophalangeal joints on the plantar surface of the foot.

4.3.9.4 Pain assessment

The pain was measured using the Wong-Baker pain rating scale (WBS). Chambers et al. (1999) report that face scales have become the most popular method to obtain children's self-reporting of pain. They found that children and parents preferred scales that they perceived to be happy and cartoon-like and suggested these be used in clinical settings. The validity of the WBS was measured by Garra et al. (2010). They aimed to evaluate a correlation between the WBS and the visual analog scale (VAS) among 120 children with chronic pain. The finding was that the mean VAS increased uniformly across WBS categories in increments of about 17 mm. ANOVA illustrated significant differences in mean VAS across face groups. Post hoc testing showed that each mean VAS was significantly different from every other mean VAS. The agreement between the WBS and VAS was excellent ($\rho = 0.90$; 95% CI = 0.86 to 0.93). No relation was found between age, sex or pain location and either pain score. Garra et al. (2010) concluded that the VAS demonstrated excellent correlation in older children with acute pain and had a uniformly increasing relationship with WBS. This finding supports the use of the WBS as an assessment tool for research on pain management in a clinical setting. Therefore, the WBS was used to identify the pain level as part of the CLIPer classification and measure pain level after each functional activity task (Figure 8).

Figure 8: Wong-Baker FACES pain rating scale

4.4 Functional activities task

The functional activities tasks aim to evaluate the compensation mechanisms for walking, single-leg balance and squat activities among non-operative children with Perthes compared to typically developing children (the control group), based on a biomechanical approach using a 3D motion analysis system. The following section describes the lab setting and procedure in detail.

4.4.1 Lab setting

The movement lab was equipped with a 3D motion analysis system (Vicon, Oxford Metrics Ltd., Oxford, UK). This system can record kinematic and kinetic aspects of movement, including trunk and lower limb motion, while the subject moves along a 15-metre walkway. Kinematic analysis was performed on data collected by ten wall-mounted cameras appropriately positioned in the laboratory to give a calibrated volume. Each camera detects reflected light from retro-reflective markers to establish the 2D marker position. Calibration of the cameras combines 2D information from each camera to establish 3D coordinates of each marker to enable the marker positions to be tracked and visualised in real-time. Before data collection, the capture area was calibrated using a calibration active T-wand (Vicon) to ensure each camera is appropriately positioned and calibrated to identify markers within a defined area of interest easily. When using optoelectronic devices, ‘ghost’ markers (faux ‘marker’ trajectories from reflections within the data collection area) can appear and be manually deleted. Spherical retro-reflective markers were placed over anatomical landmarks using double-sided marker tape with data captured at 100Hz, acceptable in walking (Hori et al. 2009). The 2D marker positions from each camera were displayed on the Vicon workstation. Since all cameras are calibrated, the cameras’ 2D marker coordinates are combined to create a visual 3D model of the marker trajectories for the whole movement. Markers (visualised on screen) were manually labelled to create link segments from which segment angles were calculated. In addition to collecting kinematic data, force data were collected from two Kistler force platforms (Kistler Instruments, Hants., UK) at 1,000 Hz. A PC workstation running the Windows 10 operating system (Microsoft Corp., USA) was used for data transfer and storage. The above components were laid out in the laboratory, as shown in Figure 9. Following further details about markers set to define the coordinate system or track motion of the individual segment.

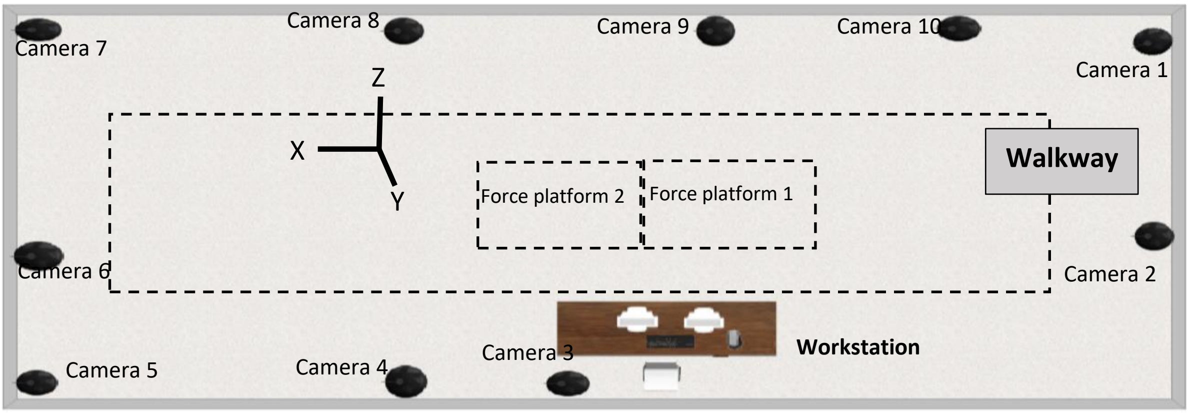


Figure 9: Schematic diagram of RCCK laboratory

4.4.2 Motion capture and force platform system reliability and validity

A ten-camera 3D motion analysis system (Vicon), with force platforms (Kistler Instruments, Hants., UK), evaluated sagittal, frontal and transverse planes for trunk, pelvis, hip, knee and ankle using a torso–lower body plug-in gait model as described in the next section. This system is considered a gold standard and has shown excellent test-retest reliability and validity (Dara Meldrum et al. 2014).

Tsushima et al. (2003) examined the test-retest reliability and inter-rater reliability of kinematic measures using the Vicon system. They evaluated kinematic data for lower limbs while walking for six unimpaired adults (age = 20 to 52, mean = 35.2 ± 6.2), which two expert physiotherapists collected. The reliability test for the study was the repeated measures design, measuring in two different trial sessions. The reliability test measured joint angle data collected by two different raters in two different trial sessions. Reflective markers were placed on 15 defined bone landmarks, including the pelvis and lower body locations according to the Vicon Clinical Manager model. Coefficients of multiple correlations (CMC) were performed to investigate the reliability between the kinematic variables across raters and sessions. Both test-retest and inter-rater reliability were high for motion in the sagittal plane (R_a = 0.971 to 0.994), the frontal plane (R_a = 0.759 to 0.977) and the transverse plane (R_a = 0.729 to 0.899), except for pelvic tilt. The researchers concluded that there is evidence for the reliability of 3D motion analysis for use in analysing human walking.

4.4.3 Motion capture calibration

Figure 10: Active T-wand

Calibration of Vicon cameras was processed to create 3D coordinates of each marker to enable the marker positions to be captured and visualised in real-time. Before data collection, the capture area was calibrated using an active calibration T-wand (Vicon) (Figure 10) to ensure each camera was perfectly positioned and calibrated to identify markers within a defined capture area. The two-dimensional marker positions from each camera were shown on the Vicon workstation. When all cameras were calibrated, the cameras' two-dimensional marker coordinates were combined to establish a visual 3D model of the marker trajectories for all movement patterns. In addition, the active T-wand was placed on the edge of the force platform to the X and Y axis to identify the origin and orientation of the laboratory and coordinate system with the X (anterior/posterior) axis, Y (medial/lateral) axis, and Z (the vertical) axis. The system was then re-synchronised to ensure the motion analysis system and force platform were accurately synched together. This calibration procedure was performed every time the RCCK lab was used.

4.5 Preparation procedures

4.5.1 Marker set and static trial calibration

Each child wore a swimsuit and had bare feet (Figure 11). The researcher placed markers on the child's body in a position of standing according to the torso–lower body plug-in the gait model. Marker positions are described in the next section. Once the markers were affixed, the Vicon system was re-synchronised with the force platform and data were visually inspected to ensure all preparation procedures had been undertaken correctly. A static subject calibration was conducted with the subject standing still for five seconds in the centre of the capture volume area to identify the local coordinates of the markers relative to each other.

Figure 11: Swimsuit

4.5.2 Marker placing

The standardised torso–lower body plug-in gait marker set (appendix xix) was used to identify joint centres and kinematic data. Reflective markers were placed on anatomical bone landmarks to define the trunk, pelvis, thigh, shank, and foot segments, as illustrated in the Kadaba guideline (Kadaba et al. 1990). The procedures followed for each marker placement are described in Table 11. Markers were placed on the skin with the subject standing.

Table 11: Plug-in Gait Model for Marker Positions

Marker		Location
Torso markers	C7	On the seventh cervical vertebra.
	T10	On the tenth thoracic vertebra.
	RBAK	On the right scapula.
	CLAV	On the clavicle on the jugular notch where the clavicle meets the sternum.
	STRN	On the xiphoid process of the sternum.
Pelvis markers	LASI RASI LPSI RPSI	Directly over the posterior and anterior superior iliac spines (ASIS) in both right and left sides. The inter-ASIS distance required for model implementation was calculated automatically by the Vicon software during the static trial.
Thigh markers	LTHI RTHI	Asymmetrically on the lateral aspect of the thigh. This asymmetry helps to distinguish between right and left sides. The right marker was placed above the left marker.
Knee markers	LKNE RKNE	The subject was asked to bend and straighten the knee for marker placement on the lateral femoral epicondyle of both right and left sides.
Tibial markers	LTIB RTIB	Asymmetrically on the lateral aspect of the leg. This asymmetry helps to distinguish between right and left sides. The right marker was placed above the left marker.
Ankle markers	LANK RANK	On the lateral malleolus on both right and left sides.
Toe markers	LTOE RTOE	On the point between the second and third metatarsal heads on the joint line on both right and left sides.
Heel markers	LHEE RHEE	On the calcaneus at the same height from the plantar surface of the foot on both right and left sides.

4.6 Trial protocols

4.6.1 Movement analysis procedure

Following the collection of the static trial, the functional activities data were collected. In the trial, the participants were asked to walk through the lab for two minutes to get familiar with walking in the lab environment. Then, the children performed three functional activities: walking, single-leg balance and squat (Figures 12 to 14). For the walking activity, all children walked at a self-selected speed along a 15-metre walkway to record data in five clean trials. A trial was discarded if both feet did not land on the force plates. For balance, the children performed a single-leg balance trial. The foot position was based on the child's preference. This balance activity was performed three times, and the children had five seconds to maintain their posture before data collection. The child first stood comfortably for the squat, then was asked to squat to the lowest point possible and return to the original standing position; this was repeated five times. All functional activities were carried out barefoot.

The researcher provided all data collection instructions to the children according to a standardised protocol to minimise possible researcher bias. In each trial, the child walked into the lab for two minutes to familiarise him/herself with the markers and with walking in this new environment. A 30-second (minimum) rest period between each test condition was used to ensure that fatigue did not become a confounding variable. It also ensured that any pain response had settled before the next task was undertaken. Where pain did not resolve to pre-task levels, the activity was stopped. The participants were given the opportunity to practise each movement twice before data collection to familiarise themselves with the protocol. When a child had completed the activities, the reflective markers were removed from their skin. Children were then allowed to change their clothes, and refreshments were provided. The whole trial session was designed to last approximately an hour and a half.

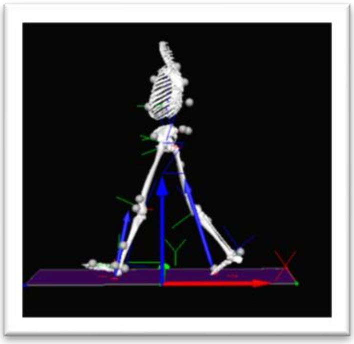


Figure 13: Walking

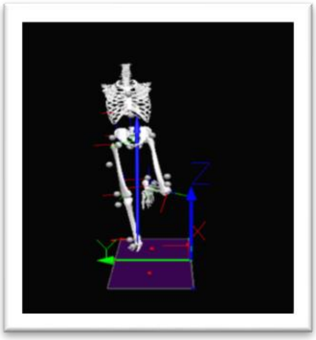


Figure 12: Single-leg balance

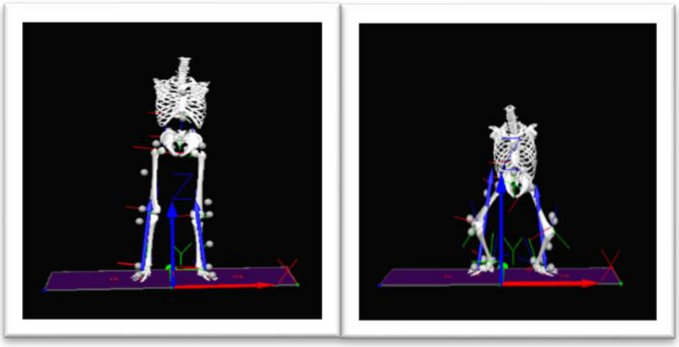
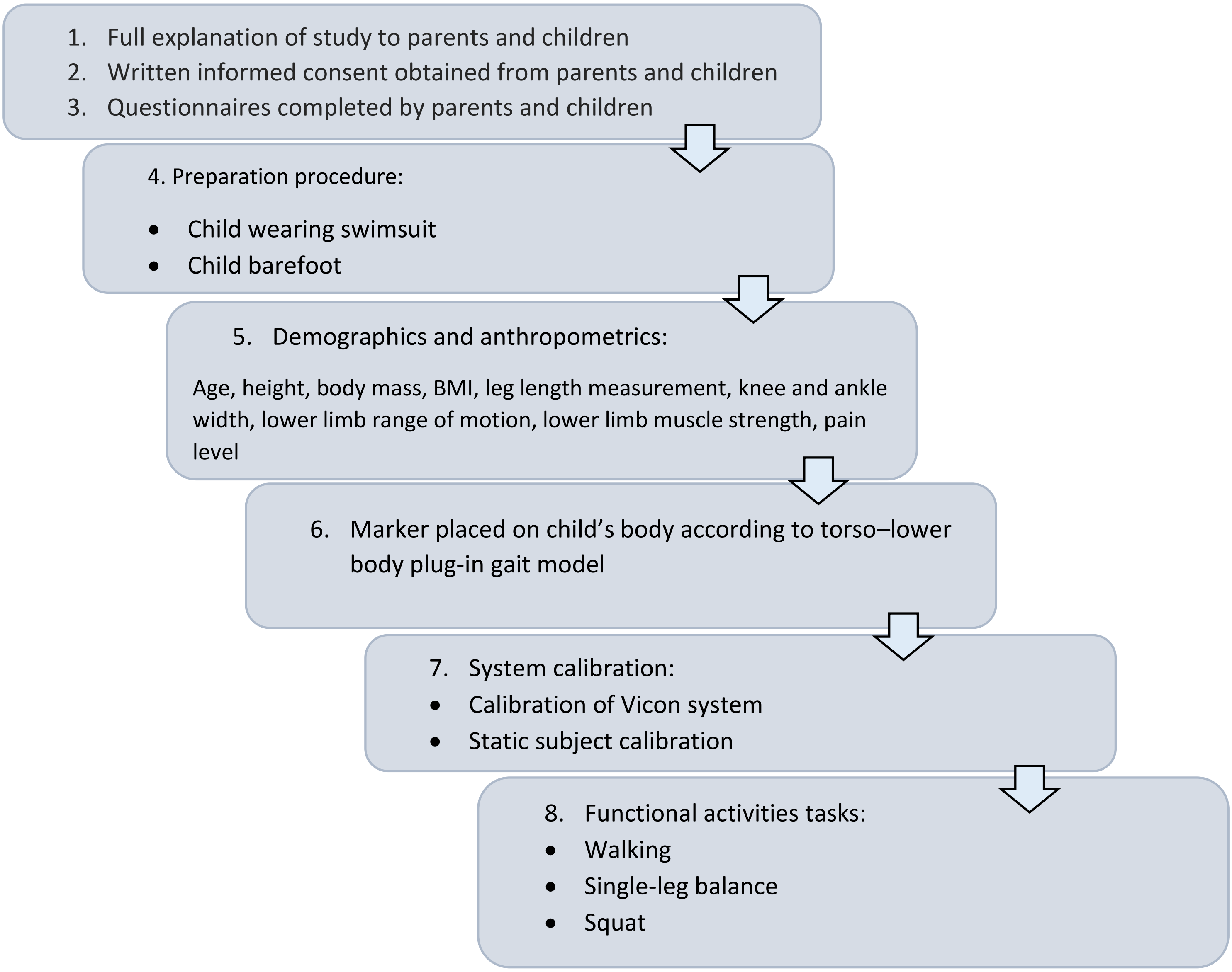


Figure 14: Squat

4.6.2 Piloting

Before data collection, two control subjects took part in a pilot study aimed at extensive piloting of the protocol procedure and marker set. First, all markers positions were evaluated to ensure that each marker could be seen by two cameras at all times. Piloting revealed that the cameras clearly detected markers. During the piloting procedure, no major issue was found except that the C7 marker was flickering on a female participant because her hair covered the marker. The researcher, therefore, provided each participating girl with a cap to cover their hair during functional activities. This piloting procedure was important for the researcher to become familiar with the measurement tools and identify the time needed for the preparation of the lab before subjects arrived. In addition, specific technical issues with the use of the Vicon system were identified in the pilot procedure: for example, the camera did not work, a problem that was solved by shutting down and restarting the computer.



1. Full explanation of study to parents and children
2. Written informed consent obtained from parents and children
3. Questionnaires completed by parents and children

4. Preparation procedure:

- Child wearing swimsuit
- Child barefoot

5. Demographics and anthropometrics:

Age, height, body mass, BMI, leg length measurement, knee and ankle width, lower limb range of motion, lower limb muscle strength, pain level

6. Marker placed on child's body according to torso–lower body plug-in gait model

7. System calibration:
- Calibration of Vicon system
- Static subject calibration

8. Functional activities tasks:
- Walking
- Single-leg balance
- Squat

Figure 15: Flow chart outlining Study Two protocol (for patient and control group)

4.7 Data processing

4.7.1 Derivation of joint angles and moment from the raw marker data

A variety of marker sets have been used in clinical gait analysis. One of the most commonly used in gait analysis is the conventional gait model (CGM) (Kadaba et al. 1990; Davis et al. 1991). The advantages and disadvantages of using the CGM markers set were reported in the Baker et al. (2018) review. The limitations of the CGM markers set are: it is only allowing three rotational degrees of freedom for hip and knee and two for ankle and very sensitive by skin movement due to the minimum number of markers and a large distance between the markers (Cereatti et al. 2007). In addition, in CGM, it is impossible to identify the position and orientation of segments independently of other segments because, in the CGM, only two tracking markers are used to provide each segment (Schwartz et al. 2004; Cereatti et al. 2007). Despite the limitations of using the CGM markers set, it is also important to acknowledge it has many advantages. The CGM has been more extensively validated than any other model (Baker et al. 2018). Moreover, the minimum number of markers set is another advantage for using the CGM in routine clinical practice in order to save time, and the effects of marker misplacement or skin movement are entirely predictable (Baker et al. 2018). According to the advantages of the CGM, this thesis considers using this model to process the functional activities data.

4.7.2 Model structure and anatomical segment definitions

The CGM model has seven segments linked in a chain by ball joints (three rotational degrees of freedom) in the sequence left foot, left tibia, left femur, pelvis, right femur, right tibia, right foot. An orthogonal coordinate system is associated with each segment. While the three-segment axes are mathematically equivalent, clinical convention defines the segment alignment in terms of the alignment of a primary axis and the rotation about this as defined by some off-axis reference point. These are defined in Table 12 according to Baker et al. (2018) review.

Table 12: Anatomical segment definition for the Conventional Gait Model		
Segment	Primary axis	Reference point
Trunk	The trunk segment is identified by three landmarks. 1. Thorax _ proximal: the midpoint between the clavicle and 7th cervical vertebra. 2.Thorax_distal: the midpoint between the sternum and 10th thorax vertebra. 3. Thorax _ anterior/posterior: the midpoint between the clavicle and sternum. Therefore, the long axis is defined along the line from the proximal to distal end.	The reference point is the mid-point between the clavicle and the 7th cervical vertebra.
Pelvis	The primary axis is the mediolateral axis running from one hip joint centre to the other.	The mid-point of the posterior superior iliac spines (PSIS).
Femur	The primary axis is that running from the hip joint centre to the knee joint centre.	The lateral epicondyle.
Tibia	The primary axis is that running from the knee joint centre to the ankle joint centre.	The lateral malleolus.
Foot	The primary axis is that running from the posterior of the calcaneus to the second metatarsal bone.	Rotation about this axis is not defined.

4.7.3 Marker placement to estimate anatomical segment position

Markers are placed in such a way that the distal segment orientations can be estimated from proximal segments. For example, the hip joint location within the pelvis coordinate system can be defined by three equations: leg length functions and ASIS to ASIS distance (Davis et al. 1991). The knee joint centre in the femur coordinate system is assumed to lie in the coronal plane at the point at which the lines from it to the hip joint centre and lateral femoral epicondyle are perpendicular, and the distance between the joint centre and epicondyle is half the measured knee width. The ankle joint centre within the tibia is specified analogously with respect to the lateral malleolus (Baker et al. 2018).

4.7.4 Gait event, Kinematic and kinetic data processing

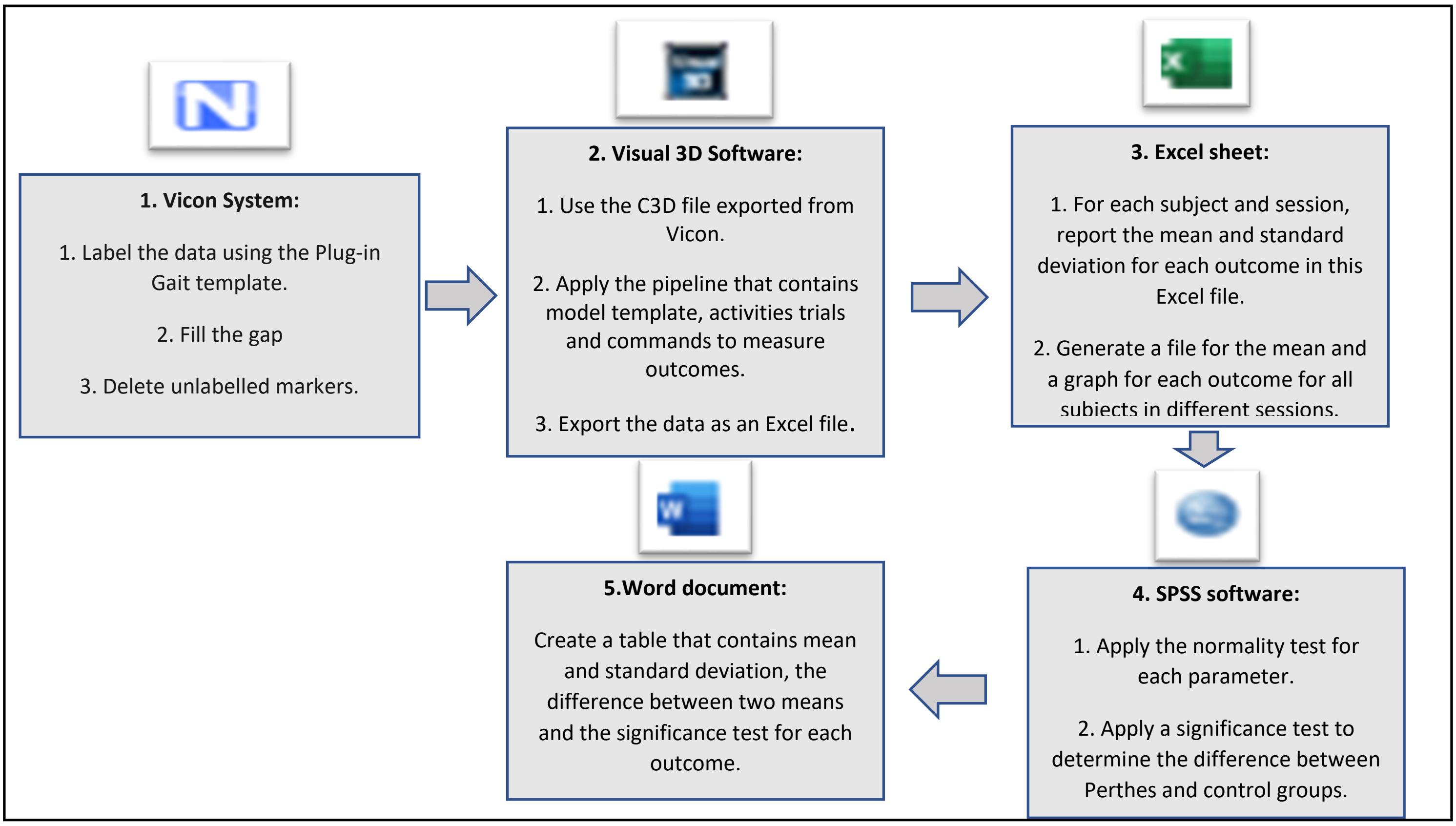
Gait Events, such as Heel Strike and Toe Off, are commonly used to identify gait cycles and normalize signals accordingly. Generally, using force platforms is the most accurate method to identify gait events automatically. These gait events were divided into two categories, which are kinematically and kinetically categories. The kinematic category includes Right Heel Strike (RHS), Right Toe Off (RTO), Left Heel Strike (LHS), Left Toe Off (LTO), while the kinetic category refers to those events that describe contact with a force platform and includes: Right On (RON), Right Off (ROFF), Left On (LON), Left Off (LOFF). All kinematic and kinetic collected data were processed using a 3D motion analysis system (Vicon, Oxford Metrics Ltd., Oxford, UK) and Visulal3D (V3D) software (Version 6 x64). To begin with, each marker was labelled for the standing and movement trials using the Vicon software. Then all trials were exported to C3D format. The V3D software was then used derived joint angles and obtain joint moments. Firstly, the C3D files were imported into V3D, and raw marker data and force data were interpolated and low pass filtered to minimise the noise and remove the high frequency. A 6Hz cut off point for kinematics data (Winter 2009), and 25Hz for force data (Schneider and Chao 1983) was applied to filter the data using a Butterworth fourth-order filter. A 6DOF model was created in V3D, which consisted of two feet segments, two shank segments, two thigh segments, a pelvic and a thorax according to the V3D motion guidelines (C-Motion 2019).

4.7.5 Deriving joint angles and joint moments

After the raw data was filtered, V3D was used to calculate joint kinematics and kinetics. Specifically, joint kinematics were obtained by applying Cardan/Euler angle calculations to determine 3D joint angles between each set of adjacent segments (Cole et al. 1993). In addition, force data was used as part of inverse dynamic calculations to derive joint moments at the hip, knee and ankle. The subject’s mass (in kilograms) were entered into the V3D to normalise the joint moment data. Kinetic data were normalised to 100% of a stance phase, while the kinematic data were normalised to 100% of a gait cycle. Then gait curves were exported as spreadsheets into Microsoft Excel to conduct the statistical analysis and construct a graphical plot of the data. This was done for each participant's trial, creating a database containing all data. Using these data, the ensemble averages from the kinematics and kinetics data were graphed for the full gait cycle and stance phases, respectively, for each subject and each movement condition (single leg balance and squat activity). Finally, from these curves, specific outcomes were calculated for each of the functional activity movements.

4.7.6 Data processing stages

Data processing was done in four stages (Figure 16). The Vicon system was used to create a template model, record functional activities, fill marker gaps, and export a C3D file in the first stage. The C3D file exported from the Vicon system was then transferred into Visual 3D software to run a pipeline to obtain relevant functional activity outcomes for each subject, exported as an Excel sheet. The Excel file was exported to SPSS software to calculate a significant level for each functional activity parameter between the control and Perthes groups. The following stage used the Excel program to calculate the mean and standard deviation for each parameter for control and Perthes groups. In addition, Excel was used to create graphs to compare Perthes data with control data to facilitate visual comparison. The following figure illustrates the data analysis procedure.



1. Vicon System:

1. Label the data using the Plug-in Gait template.

2. Fill the gap

3. Delete unlabelled markers.

2. Visual 3D Software:

1. Use the C3D file exported from Vicon.

2. Apply the pipeline that contains model template, activities trials and commands to measure outcomes.

3. Export the data as an Excel file.

3. Excel sheet:

1. For each subject and session, report the mean and standard deviation for each outcome in this Excel file.

2. Generate a file for the mean and a graph for each outcome for all subjects in different sessions.

4. SPSS software:

1. Apply the normality test for each parameter.

2. Apply a significance test to determine the difference between Perthes and control groups.

5.Word document:

Create a table that contains mean and standard deviation, the difference between two means and the significance test for each outcome.

Figure 16: Data analysis procedure

4.8 Outcome measures

This section highlights the outcome measures for walking, single-leg balance and squat tasks, measured by the Vicon system. The outcome measures were considered on the right side for the control group and on both affected and non-affected sides for the Perthes group. This procedure is important as children with Perthes demonstrate movement compensation in both sides, as reported in the Perthes literature. Table 13 summarises the outcome measures; it is followed by details and justification of outcome measures for each functional activity.

Table 13: Outcome measures

Functional activity	Walking	Single-leg balance	Squat
Temporospatial parameters	Speed, stride width, stride length, step length, stance phase, swing phase, cadence	COP area, COP velocity	---
Kinematic parameters	Trunk, pelvic, hip, knee in sagittal, frontal and transverse planes, Ankle dorsi/plantar flexion, and foot progression (Maximum degree, Minimum degree and range of motion (ROM))	Trunk, pelvic and hip Maximum degree, Minimum degree in sagittal, frontal and transverse planes	Trunk, pelvic, hip, knee in sagittal, frontal and transverse planes, Ankle dorsi/plantar flexion, and foot progression (Maximum degree, Minimum degree and range of motion (ROM))
Kinetic parameters	Peak hip extensor and abduction moment, peak knee abductor moment, peak hip, knee and ankle power, peak vertical ground reaction force (GRF)	Peak hip extensor and abduction moment, peak hip power, peak vertical (GRF)	Peak hip extensor and abduction moment, peak hip power, peak knee abductor moment, peak vertical (GRF)

4.8.1 Walking outcome measures

The outcome measures for walking were considered in three planes (sagittal, frontal and transverse) and included temporospatial, kinematic and kinetic parameters. These outcomes are described in the following paragraphs.

4.8.2 Temporospatial outcome measures

The temporospatial outcome measures for walking were speed, stride width, stride length, step length, stance phase, swing phase and cadence. Gait speed is an important parameter that should be considered in each gait study. A systematic review with the meta-analysis by Fukuchi et al. (2019) evaluated 20 studies to identify the effect of gait speed on temporospatial parameters, joint kinematics, joint kinetics and GRF in young and older populations and control groups. This review suggested that gait speed influenced gait parameters of different populations with respect to the amplitude of temporospatial parameters, joint kinematics and kinetics and GRF. A slower walking speed decreased other gait parameters, while fast walking increased gait parameters. The review recommends considering walking speed not only in control subjects but also in subjects with pathological conditions. There is a strong relationship between walking speed and stride length, step length and cadence, as reported by Menz et al. (2003). Walking speed is defined as the distance covered by the body per second. Step length is defined as the distance between two heels of different legs, while stride length is defined as the distance between heel strikes of the same leg. In normal gait, stride length is equal to double the step length. For walking stability, stride width, stance phase and swing phase measurements are essential parameters (Ko et al. 2007). Kurz et al. (2012) report that children with musculoskeletal impairment (such as children with Perthes) presented with unstable walking patterns as they spent more time in the stance phase and displayed more variability in stride width. Stride width is defined as the lateral distance between the feet (Figure 2). The stance phase is when a foot is on the floor and represents approximately 60% of the gait cycle. The swing phase is the time when the foot is in the air and represents approximately 40% of the gait cycle. Cadence is defined as the number of steps per second. Children with Perthes displayed lower walking speed, shorter stride and step length, longer stance phase and increased cadence than control groups (Svehlik et al. 2012; Westhoff et al. 2012; Karimi et al. 2019).

4.8.3 Kinematic and kinetic parameters

Children with Perthes display compensation mechanisms in the trunk, pelvis, hip, knee and ankle joints. The trunk leans towards the affected stance limb during single-leg stance (Stief et al. 2014), while the pelvis shows two distinct gait patterns, both deviating from the normal pattern, especially during the single-leg stance phase (Svehlik et al. 2012). In addition, the hip joint demonstrates a limitation in ROM, particularly in hip extension, abduction and internal rotation (Westhoff et al. 2012). Moreover, knee ROM is affected in Perthes groups compared to controls, as Stief et al. (2016) report. The ankle shows two compensation patterns, out-toeing and in-toeing, during walking (Yoo et al. 2008). In addition, the kinetic parameters are affected in children with Perthes due to weakness in the hip abductor muscle (Westhoff et al. 2012). This weakness affects hip kinetic parameters and knee abductor moment (Stief et al. 2014). The total work done at hip, knee and ankle joints is affected in the Perthes side compared to the non-affected side and control groups (Westhoff et al. 2012). Moreover, the vertical GRF is considered as a walking outcome because it is important to measure kinetic parameters and their relation to walking speed (Keller et al. 1996; Stief et al. 2014). Therefore, in the present study, the trunk, pelvis, hip, knee and ankle ROM, hip extensor moment, hip abductor moment, knee abductor moment, ankle extensor moment, hip, knee and ankle power and vertical GRF are considered as walking outcomes measures in three planes (sagittal, frontal and transverse). Based on the previous systematic review chapter, these outcomes are shown to be the ones most affected in children with Perthes.

4.8.4 Single-leg balance outcome measures

Single-leg balance is an essential element in most functional activities, for example, during the single-limb stance phase of walking (as described in the literature review chapter). The outcomes for the single-leg balance task were the centre of pressure (COP) area and velocity, trunk ROM, pelvis ROM, hip ROM, hip extensor moment, hip abductor moment, hip power and vertical GRF. It is essential to measure postural stability as children with Perthes demonstrate prolonged time in the stance phase, which indicates that stability is affected by Perthes disease (Svehlik et al. 2012). In addition, Karimi and Esrafilian (2013) found that children with Perthes were significantly unstable compared to healthy children in the mediolateral of (COP) direction. To measure postural stability, COP area, velocity, and vertical GRF are the most common measures reported by Ruhe et al. (2010) in their systematic review. The COP area was measured in this thesis based on visual3D software by Creating a LINK_MODEL_BASED signal called the COP_PATH. The command checks all contacts between the specified segment and any force platform. The signal is then transformed (or resolved) into the specified local coordinate system.

In addition, trunk, pelvic and hip ROM in three planes (sagittal, frontal and transverse), hip extensor moment, hip abductor moment, and hip power were considered further outcome measures. These are related to Perthes disease as the hip adductor muscle demonstrates weakness that leads the trunk to lean and the pelvis to drop (Svehlik et al. 2012; Stief et al.

2014). Therefore, measuring these outcomes when children with Perthes perform single-leg balance will provide a clear picture of postural stability.

4.8.5 Squat outcome measures

The squat activity is considered a multi-joint movement that challenges lower limb muscles in the entire extension chain (Eken et al. 2017). This activity is frequently performed during routine daily activities or as part of an exercise, for example, sit-to-stand and jumping (Stevens et al. 2018). As the squat activity is a multi-joint movement and children with Perthes show compensation mechanisms in the trunk and lower limb joints during walking, it is important to evaluate trunk, pelvis, hip, knee and ankle ROM during the squat activity. As children with Perthes disease demonstrated weakness in the hip adductor muscle, hip extensor moment, hip abductor moment, knee abductor moment, hip power, and the peak of verticle GRF are important to investigate the loading on the hip joint as supported by Wurm et al. (2010) and Pantak (2017).

4.9 Methods consideration of human motion analysis

Derrick et al. (2020) conduct a review to discuss the major issues in the definition, calculation, and interpretation of intersegmental forces and moments in human motion analysis and make final recommendations on these matters with guidance from relevant papers in the literature. The goal of this review was to eliminate the most frequent sources of error and confusion in the field of human motion analysis so that research can be correctly interpreted and replicated. They provide a standard motion analysis method that is recommended for each study aiming to analyse human movement. The standard motion analysis method includes seven aspects: anthropometric modelling, joint centre estimation, signal processing, method of calculation, coordinate system, evaluation perspective (internal or external), and normalization. The following table 14 provides information on how this thesis methods follow the recommendation of Derrick et al. (2020) review.

Table 14: Methods consideration of human motion analysis		
Methods Concern	Derrick et al. (2020) Recommendation	Thesis Methods
1) Anthropometric model	The anthropometric model used to estimate body segment parameters must be detailed in order for results to be replicated. It includes procedures for estimating moments of inertia, mass, and centre of mass locations. The sample for which regression equations were established should be consistent with the subjects being studied.	This thesis used visual3D software that required inserting each child's height, mass, leg length, knee and ankle width to compute the position and orientation of body segment based on the regression equation.
2) joint centres	The joint centre position is used to define the moment arm of the force acting on the segment under analysis, and the way measured may influence the estimation of the intersegmental moment. Therefore, the method identified joint centre should be clearly reported in the method.	Based on the conventional gait model, the joint centre has been identified as follows: the hip joint location within the pelvis coordinate system can be defined by three equations: leg length functions and ASIS to ASIS distance (Davis et al. 1991). The knee joint centre in the femur coordinate system is assumed to lie in the coronal plane at which the lines from it to the hip joint centre and lateral femoral epicondyle are perpendiculars, and the distance between them the joint centre and epicondyle is half the measured knee width. The ankle joint centre within the tibia is specified analogously with respect to the lateral malleolus (Baker et al. 2018).
3) Signal processing	Both kinematic and kinetic sampling frequencies must be clearly identified. The smoothing method should be identified, and the degree of smoothing (typically in the form of the frequency response) should be noted. The technique used to differentiate the data and any specialized techniques such as optimized cut-offs, resampling of data and procedures to minimize artefact should be detailed and cited.	The C3D files were imported into Visual3D software, and raw marker data and force data were interpolated and low pass filtered to minimise the noise and remove the high frequency. A 6Hz cut off point for kinematics data (Winter 2009), and 25Hz for kinetics (Schneider and Chao 1983) was applied to filter the data using a Butterworth fourth-order filter.
4) Method of calculation	Static analysis of the human body should be restricted to static situations. Newton-Euler and Lagrange formulations of intersegmental moments are mathematically equivalent, but the method should be identified because their sensitivity to signal processing methods can be different. Forward or inverse dynamics procedures also need to be specified.	A static subject calibration was conducted with the subject standing still for five seconds in the centre of the capture volume area to identify the local coordinates of the markers relative to each other. Joints kinematics were obtained by applying Cardan/Euler angle calculations to determine 3D joint angles between each set of adjacent segments (Cole et al. 1993). In addition, force data was used as part of inverse dynamic calculations to derive joint moments at the hip, knee and ankle.
5) Coordinate system	The choice of the coordinate system (global coordinate system, proximal segment coordinate system, distal segment coordinate system, or joint coordinate system) highly influences the intersegmental forces and moments. Therefore, the coordinate system used to	The active T- wand was used to identify the origin and orientation of the laboratory and coordinate system. The X is referred to (anterior/posterior) axis, Y is referred to (medial/lateral) axis, and Z is referred to (the vertical) axis.

	interpret the intersegmental forces and moments must be carefully considered and reported.	To identified proximal segment coordinate, the Baker et al. (2018) recommendation has been used in this thesis as follow: 1.Trunk: (thorax with respect to pelvis coordinate system): A. Internal/external rotation: rotation of the medio-lateral axis about the vertical axis. B. Obliquity (up/down): rotation of the medio-lateral axis out of the horizontal plane. C. Anterior/posterior tilt: rotation around the medio-lateral axis. 2. Pelvis (with respect to global coordinate system): A. Internal/external rotation: rotation of the medio-lateral axis about the vertical axis. B. Obliquity (up/down): rotation of the medio-lateral axis out of the horizontal plane. C. Anterior/posterior tilt: rotation around the medio-lateral axis. 3. Hip (femur with respect to pelvis coordinate system): A. Flexion/extension: rotation of the proximal distal axis about the medio-lateral axis. B. Ad/abduction: rotation of the proximal-distal axis out of the sagittal plane. C. Internal/external rotation: rotation around the proximal-distal axis. 4. Knee (tibia with respect to femur coordinate system): A. Flexion/extension: rotation of the proximal distal axis about the medio-lateral axis. B. Ad/abduction: rotation of the proximal-distal axis out of the sagittal plane. C. Internal/external rotation: rotation around the proximal-distal axis. 5. Ankle (foot with respect to tibia coordinate system): Dorsiflexion/plantarflexion: rotation of the proximal distal axis about the medio-lateral axis. 6. Foot (with respect to global coordinate system): Foot progression (in/out): rotation of the proximal-distal axis out of the “sagittal” plane.
6) Evaluation perspective (internal or external)	Whether intersegmental forces and moments are presented as internal or external can be determined by the research question being asked but may also be dependent on the perspective that the researcher is trying to convey. A clear statement of this perspective is essential to communicating concepts in the paper.	The External evaluation prospective has been considered in this thesis.
7) Normalization	Normalization of data is often necessary if groups are dissimilar on specific variables such as mass or height.	The subject’s mass (in kilograms) were entered into the V3D to normalise the joint moment data. Kinetic data was normalised to 100% of a stance phase, while the kinematic data were normalised to 100% of a gait cycle.

4.10 Intra-rater reliability of gait (Reliability study)

4.10.1 Introduction

Movement analysis labs are frequently used to evaluate walking activity in child populations, as demonstrated in previous systematic review study; therefore, it is essential to establish the reliability study on placing markers and the reliability of typically developing children walking to identify the sources of error associated with collecting movement data. As discussed previously in the literature review chapter, there are three primary sources of error that might affect the quality of movement data such as difference in marker position (Taylor et al. 2005; Sangeux et al. 2011; Kratzenstein et al. 2012), error due to soft tissue movement and subjects who can modify their walking pattern (Baker 2006). To resolve these issues with movement data, Baker et al. (2013) suggest checking the reliability of marker placing to ensure the researcher's reliability in placing markers on subjects. In addition, Baker et al. (2013) recommend checking the reliability of walking data as children may change their walking patterns over time, which could influence gait outcomes. Therefore, the main objective of this reliability study is to establish the reliability of the researcher when placing markers and the reliability of typically developing children walking on gait outcome including temporospatial, kinematic and kinematic parameters in two sessions.

4.10.1a study objectives

The objectives of this study are a) to investigate the lead project researcher's reliability in placing markers in static positions, b) to examine the reliability of typically developing children walking between two sessions to identify the source of error before collecting movement data from children with Perthes disease.

4.10.1b Research question and Hypothesis

Q1: Is the lead project researcher reliable in placing the markers on typically developing children in a static position between two sessions?

H1: The lead project researcher has received extensive training in gait analysis; thus, the researcher will demonstrate high reliability in placing the markers on typically developing children in static position between two sessions using the Conventional Gait Model.

Q2: Are the typically developing children reliable when walking in terms of temporospatial, kinematic and kinetic parameters.?

H2: Typically developing children will demonstrate high reliability when walking in terms of temporospatial, kinematic and kinetic parameters as found in Gorton et al. (1997), Steinwender et al. (2000) and McSweeney et al. (2020) literature.

4.10.2 Methods

The study design is intra-rater reliability, which aims to establish the reliability of the lead project researcher in placing markers on typically developing children and the reliability of walking parameters for typically developing children across two sessions. The ethical consideration, detailed protocol and data analysis procedure were described previously in this method chapter (see section 4.3 and 4.4). Out of the 15 typically developing children from the control group (described earlier in this chapter in section 4.3.8), 13 attended a second session in the RCCK lab (Cardiff University, Wales, UK). An intra-rater reliability study design was employed for marker placement and where each child walked in the two sessions. Sessions took place five days apart to negate any potential learning effects between sessions.

4.10.3 Sample size

To assess the sample size needed to measure the reliability of marker placement and the reliability of typically developing children walking between sessions, a study by Walter et al. (1998) was considered. The likelihood of committing type I and type II errors was set at $\alpha = 0.05$ and $\beta = 0.2$. Table II in Walter et al. (1998) study shows the required value of sample size (k) for typical values of (2), and according to the values of $p0$=0.4 and $p1$=0.8. Therefore, the required sample size for this test-retest study is 15 subjects. However, as two children were not able to attend the second session, only 13 subjects were included. This number of 13 participants was comparable to other reliability studies such as Stolze et al. (1998); Noonan et al. (2003), and Eve et al. (2006) studies.

4.10.4 Protocol

The protocol for biomechanical movement data quality for marker placement and between-session reliability was divided into two phases. The first phase tested the reliability of the lead project researcher in placing markers in the static position. The static position was measured with the child standing still. The z-axis (vertical) was considered to measure the height of the marker position and compare the marker's location between sessions. Retro-reflective markers (Vicon) were attached (using double-sided marker tape) over the following anatomical positions: the spinous process of C7, T10, right scapula, clavicle (on the jugular notch where the clavicle meets the sternum), sternum (on the xiphoid process), left anterior superior iliac spine, right anterior superior iliac spine, left posterior superior iliac spine, right posterior superior iliac spine, left thigh, left knee, left tibia, left ankle, left heel, left toe, right thigh, right knee, right tibia, right ankle, right heel, and right toe.

The second phase measured the between-day reliability of the parameters for children walking, including temporospatial, kinematic and kinetic parameters, similar to the gait parameters described previously. The mean and standard deviation of each marker position and walking parameter were compared between sessions.

4.10.5 Data processing

The data processing is similar to the 4.7 section in this methods chapter.

4.10.6 Statistical Analysis

Intraclass correlation coefficients (ICC), standard errors of measurements (SEMs) and Minimum Detectable Change (MDC) were calculated in SPSS software (Version 27) for the reliability of marker placement and for gait parameter reliability between sessions, including temporospatial, kinematic and kinetic outcomes. To interpret the relevance of the ICC reproducibility level, an ICC of >0.80 was considered “excellent”, an ICC of 0.61–0.79 “substantial”, 0.40–0.60 “moderate”, and <0.40 “slight” (Landis and Koch 1977; Portney and Watkins 2008). When ICC used alone, it will not provide a full picture of the reliability (McGinley et al. 2009). Therefore, the standard error of measurement (SEM) was calculated by the following equation: SEM= pooled SD1 X √(1-ICC). As the pooled SD= √(SD 1st session)^2 + (SD 2nd session)^2/2, with low values are indicating good reliability (Denegar and Ball 1993; Cohen 2013). To facilitate clinical interpretation, the Minimum Detectable Change (MDC) represents whether a change observed between tests is a ‘real’ alteration, rather than a ‘random’ variation in measurements (Wilken et al. 2012). To calculate MDC, the following equation was used: MDC= SEM X 1.96 X √**2.**

4.10.7 Results

4.10.7.1 Demographic data

Table 15 presents demographic data for the 13 typically developing children who participated in walking in the overground movement analysis lab in two sessions. There were seven boys and six girls with a mean age of 7.9 years; height, body mass and BMI were 1.25 m, 25.26 kg and 15.94, respectively. The mean leg length was 0.694 m.

Table 15: Demographic data for the reliability study

	Mean (± SD)
Number of control subjects	13
Male	7
Female	6
Age (years)	7.9 (± 1.79)
Height (m)	1.25 (± 0.11)
Body Mass (kg)	25.26 (± 5.29)
Body mass index	15.94 (± 1.62)
Leg length (m)	0.694 (± 0.06)

Key: m: metre; kg: kilogram; s: second

4.10.7.2 Reliability of marker placement in the static position

Table 16 presents the reliability of marker placing in the static position and shows substantial to excellent result (ICC>0.6), except at RANK was moderate (ICC = 0.517). In addition, the SEM and MDC values in all landmark markers were below 0.013 m and 0.037 m, respectively.

Table 16: Reliability of marker placement in the static position

Marker	**Session 1 Mean (± SD)**	**Session 2 Mean (± SD)**	**Difference (session1 – session2) Mean (± SD)**	**ICC**	**SEM**	**MDC**
LASI (m)	0.672 (± 0.066)	0.667(± 0.069)	0.004 (± 0.003)	0.992	0.004	0.012
RASI (m)	0.672 (± 0.065)	0.667 (± 0.069)	0.005 (± 0.004)	0.992	0.004	0.012
LPSI (m)	0.710 (± 0.070)	0.702 (± 0.071)	0.008 (0)	0.992	0.004	0.012
RPSI (m)	0.705 (± 0.071)	0.696 (± 0.071)	0.009 (± 0.000)	0.992	0.004	0.012
LTHI (m)	0.381 (± 0.039)	0.381 (± 0.046)	0.000 (± 0.007)	0.957	0.006	0.017
LKNE (m)	0.316 (± 0.032)	0.314 (± 0.037)	0.002 (± 0.005)	0.922	0.007	0.019
LTIB (m)	0.136 (± 0.026)	0.132 (± 0.025)	0.004 (± 0.001)	0.88	0.006	0.017
LANK (m)	0.025 (± 0.014)	0.022 (± 0.008)	0.004 (± 0.006)	0.814	0.003	0.010
LHEE (m)	0.017 (± 0.009)	0.014 (± 0.009)	0.004 (0)	0.867	0.002	0.006
LTOE (m)	0.008 (± 0.011)	0.006 (± 0.005)	0.002 (± 0.005)	0.772	0.003	0.008
RTHI (m)	0.516 (± 0.053)	0.499 (± 0.049)	0.017 (± 0.003)	0.861	0.013	0.037
RKNE (m)	0.314 (± 0.034)	0.314 (± 0.034)	0	0.959	0.005	0.013
RTIB (m)	0.237 (± 0.025)	0.238 (± 0.022)	0.000 (± 0.004)	0.692	0.009	0.026
RANK (m)	0.020 (± 0.012)	0.019 (± 0.009)	0.001 (± 0.003)	0.517	0.005	0.014
RHEE (m)	0.014 (± 0.010)	0.011 (± 0.008)	0.003 (± 0.002)	0.651	0.004	0.010
RTOE (m)	0.013 (± 0.011)	0.011 (± 0.008)	0.002 (± 0.004)	0.634	0.004	0.011

Key: LASI: left anterior superior iliac spine; RASI: right anterior superior iliac spine; LPSI: left posterior superior iliac spine; RPSI: right posterior superior iliac spine; LTHI: left thigh; LKNE: left knee; LTIB: left tibia; LANK: left ankle; LHEE: left heel; LTOE: left toe; RTHI: right thigh; RKNE: right knee; RTIB: right tibia; RANK: right ankle; RHEE: right heel; RTOE: right toe; SD: standard deviation; ICC: intraclass correlation coefficient; SEM: standard error measurement; m: metre.

4.10.7.3 Reliability of children walking in the overground movement analysis lab

4.10.7.3a Temporospatial parameters

Table 17 presents the temporospatial parameters, which showed excellent repeatability of ICC>0.8 for all parameters, except in stride width that represented substantial value (ICC = 0.607). The SEM and MDC values were less than 0.035 measurement units in all temporospatial parameters, except cadence that showed (SEM = 2.718) and (MDC = 7.533) measurement units, respectively.

Table 17: Reliability of temporospatial parameters

	Session 1 Mean (± SD)	**Session 2 Mean (± SD)**	**Difference (session1 – session2) Mean (± SD)**	**ICC**	**SEM**	**MDC**
Speed (m/s)	1.19 (± 0.149)	1.188 (± 0.139)	0.002 (± 0.01)	0.907	0.031	0.086
Stride width (m)	0.097 (± 0.017)	0.105 (± 0.018)	-0.008 (± 0.001)	0.607	0.008	0.022
Stride length (m)	1.145 (± 0.166)	1.127(± 0.127)	0.018 (± 0.039)	0.94	0.026	0.071
Step length (m)	0.563 (± 0.033)	0.553 (± 0.04)	0.01 (± 0.007)	0.822	0.011	0.030
Stance time (s)	0.573 (± 0.062)	0.572 (± 0.068)	0.001 (± 0.006)	0.94	0.011	0.031
Swing time (s)	0.371 (± 0.055)	0.373 (± 0.046)	-0.002 (± 0.009)	0.874	0.013	0.035
Cadence (step/min)	125.48 (± 12.288)	129.93 (± 15.755)	-4.452 (± 3.467)	0.926	2.718	7.533

Key: SD: standard deviation: ICC: intraclass correlation coefficient; SEM: standard error measurement; m: metre; s: second; min: minute.

4.10.7.3b Kinematic parameters

Table 18 shows the kinematic data, which demonstrates moderate to excellent repeatability (ICC > 0.4) in most kinematic parameters, except the minimum of the trunk and hip adduction, where an ICC of 0.3 indicates slight repeatability. The SEM and MDC values were less than 5° and 15° for most kinematic parameters, respectively. However, minimum hip rotation, knee add/abduction ROM, and maximum foot progression showed higher SEM value > 5°, whilst the MDC was higher in minimum hip rotation, knee maximum adduction, and ankle maximum rotation (MDC>15 °). In Figure 17, the kinematic walking pattern was similar between sessions in most of the parameters. Reliability between sessions was higher in the sagittal plane in all parameters. In the frontal plane, the graph is consistent in most parameters, except in trunk obliquity ROM and knee adduction/abduction ROM in the swing phase. The graphs for the transverse plane are consistent in most parameters, except in hip rotation and foot progression.

Table 18: Reliability of kinematic parameters

		Session 1 Mean (± SD)	Session 2 Mean (± SD)	Difference (session1-session2) Mean (± SD)	ICC	SEM	MDC
Trunk	Maximum anterior tilt (°)	-12.879 (±7.498)	-13.548 (±8.101)	0.669 (±0.603)	0.830	2.276	6.308
	Minimum anterior tilt (°)	-15.459 (±6.843)	-15.818 (±6.837)	0.359 (±0.006)	0.715	2.582	7.157
	ROM (°)	2.580 (±0.655)	2.270 (±1.263)	0.31 (±0.608)	0.683	0.401	1.110
	Maximum adduction tilt (°)	4.508 (±4.101)	2.726 (±4.456)	1.782 (±0.355)	0.489	2.165	6.000
	Minimum adduction tilt (°)	-4.247 (±2.893)	-3.978 (±3.67)	-0.269 (±0.777)	0.350	1.884	5.222
	ROM (°)	8.755 (±1.208)	6.704 (±0.787)	2.051 (±0.421)	0.569	0.473	1.312
	Maximum rotation (°)	10.743 (±4.795)	10.555 (±4.011)	0.188 (±0.784)	0.633	1.894	5.249
	Minimum rotation (°)	-10.256 (±3.557)	-19.004 (±2.612)	8.748 (±0.945)	0.564	1.457	4.039
	ROM (°)	20.999 (±1.239)	19.558 (±1.400)	1.441 (±0.161)	0.849	0.363	1.007
Pelvic	Maximum anterior tilt (°)	15.086 (±7.697)	15.575 (±8.127)	-0.489 (±0.43)	0.760	2.742	7.600
	Minimum anterior tilt (°)	12.762 (±6.840)	13.470 (±6.845)	-0.708 (±0.005)	0.727	2.528	7.007
	ROM (°)	2.323 (±0.856)	2.105 (±1.283)	0.218 (±0.427)	0.749	0.386	1.071
	Maximum adduction tilt (°)	6.199 (±3.696)	4.512 (±4.368)	1.687 (±0.672)	0.673	1.636	4.535
	Minimum adduction tilt (°)	-5.92 (±2.707)	-5.954 (±3.721)	0.034 (±1.014)	0.534	1.571	4.353
	ROM (°)	12.121 (±0.988)	10.466 (±0.647)	1.655 (±0.341)	0.408	0.454	1.259
	Maximum rotation (°)	9.902 (±5.139)	9.003 (±3.864)	0.899 (±1.275)	0.523	2.220	6.154
	Minimum rotation (°)	-10.612 (±3.591)	-10.318 (±2.369)	-0.294 (±1.222)	0.637	1.296	3.592
	ROM (°)	20.514 (±1.547)	19.321 (±1.495)	1.193 (±0.052)	0.838	0.433	1.200
Hip	Maximum flexion (°)	39.211 (±9.255)	38.903 (±11.442)	0.308 (±2.187)	0.865	2.704	7.494
	Minimum flexion (°)	-7.303 (±6.792)	-6.730 (±5.68)	-0.573 (±1.112)	0.716	2.359	6.539
	ROM (°)	46.515 (±2.464)	45.633 (±5.763)	0.882 (±3.299)	0.839	1.257	3.485
	Maximum adduction (°)	7.174 (±4.412)	6.184 (±4.699)	0.99 (±0.287)	0.559	2.140	5.932
	Minimum adduction (°)	-2.539 (±3.573)	-3.647 (±3.4)	1.108 (±0.173)	0.328	2.022	5.604
	ROM (°)	9.713 (±0.839)	9.831 (±1.299)	-0.118 (±0.46)	0.670	0.444	1.231
	Maximum rotation (°)	-2.571 (±16.137)	1.977 (±14.359)	-4.548 (±1.778)	0.830	4.453	12.343
	Minimum rotation (°)	-15.947 (±10.930)	-12.728 (±11.725)	-3.219 (±0.795)	0.459	5.895	16.340
	ROM (°)	13.376 (±5.207)	14.705 (±2.634)	-1.329 (±2.573)	0.809	1.275	3.534
Knee	Maximum flexion (°)	61.031 (±13.258)	62.536 (±10.503)	-1.505 (±2.775)	0.797	3.810	10.562
	Minimum flexion (°)	1.790 (±5.784)	0.639 (±5.537)	1.151 (±0.247)	0.571	2.622	7.268
	ROM (°)	59.240 (±7.474)	61.897 (±4.965)	-2.657 (±2.509)	0.793	2.041	5.658
	Maximum adduction (°)	10.622 (±9.783)	6.98 (±15.899)	3.642 (±6.116)	0.636	5.631	15.609
	Minimum adduction (°)	2.692 (±3.667)	2.083 (±2.397)	0.609 (±1.27)	0.825	0.916	2.540
	ROM (°)	7.93 (±6.116)	4.897 (±13.503)	3.033 (±7.387)	0.468	5.406	14.985
Ankle dorsi/plantarflexion	Maximum flexion (°)	6.794 (±7.410)	7.275 (±9.191)	-0.481 (±1.781)	0.589	3.784	10.490
	Minimum flexion (°)	-16.807 (±3.556)	-16.871 (±4.793)	0.064 (±1.237)	0.448	2.217	6.145
	ROM (°)	23.602 (±3.853)	24.145 (±4.398)	-0.543 (±0.545)	0.679	1.656	4.591
Foot progression	Maximum rotation (°)	5.378 (±15.604)	1.049 (±21.617)	4.329 (±6.013)	0.805	5.886	16.316
	Minimum rotation (°)	--8.587 (±9.341)	-17.478 (±13.954)	26.065 (±4.613)	0.813	3.631	10.064
	ROM (°)	13.965 (±6.263)	18.527 (±7.663)	-4.562 (±1.4)	0.722	2.609	7.232

Key: SD: standard deviation; ICC: intraclass correlation coefficient; SEM: standard error measurement.

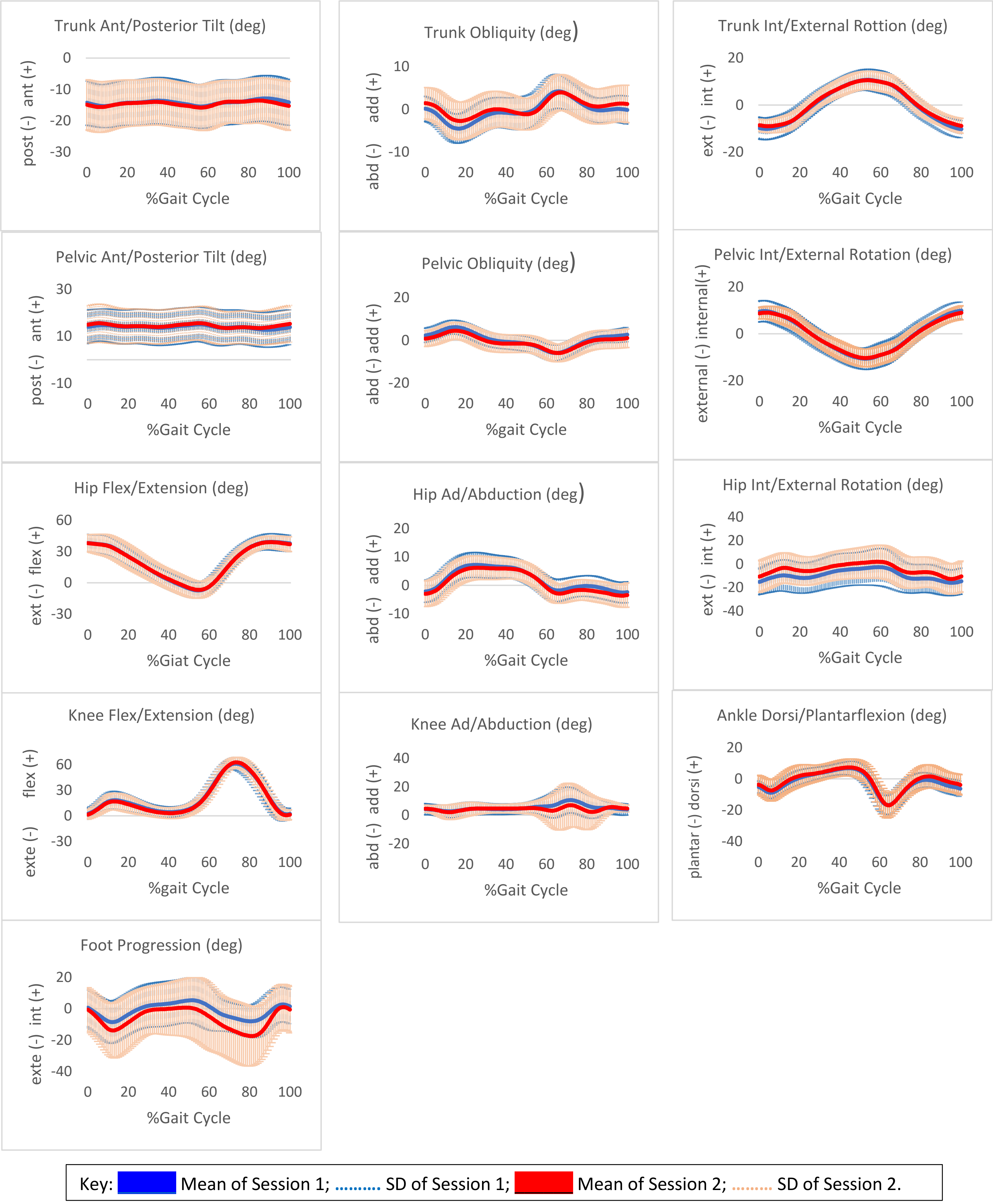


Figure 17: Reliability of kinematic walking data

4.10.7.3c Kinetic parameters

Table 19 presents the kinetic parameters, most of which show excellent repeatability of ICC>0.8. The peak of Hip power and Peak of knee power showed the moderate reproducibility value of ICC>0.5. The SEM and MDC were lower than 1.00 measurement units for all kinetic parameters, except in peak of knee power (MDC=1.381). Figure 18 shows a reliability pattern between sessions for all kinetic walking parameters, except in the hip power graph.

Table 19: Reliability of kinetic parameters

	Session 1 Mean (± SD)	**Session 2 Mean (± SD)**	**Difference (session1 – session2) Mean (± SD)**	**ICC**	**SEM**	**MDC**
Peak hip extensor moment (Nm/kg)	0.475 (±0.385)	0.471 (±0.422)	0.004 (±0.037)	0.916	0.083	0.229
Peak hip abductor moment (Nm/kg)	0.539 (±0.329)	0.566 (±0.324)	0.027 (±0.005)	0.909	0.070	0.193
Peak hip power (W/kg)	1.011 (±0.801)	1.094 (±0.903)	-0.083 (±0.102)	0.654	0.355	0.984
Peak knee abductor moment (Nm/kg)	0.123 (±0.029)	0.119 (±0.026)	0.004 (±0.003)	0.937	0.005	0.014
Peak knee power (W/kg)	0.456 (±0.940)	0.462 (±1.102)	0.006 (±0.162)	0.527	0.498	1.381
Peak ankle extensor moment (Nm/kg)	1.091 (±0.298)	1.063 (±0.247)	0.028 (±0.051)	0.972	0.032	0.090
Peak ankle power (W/kg)	2.289 (±0.983)	2.308 (±1.005)	0.019 (±0.022)	0.886	0.237	0.658
Peak vertical GRF (%BW)	1.179 (±0.211)	1.244 (±0.205)	-0.065 (±0.006)	0.878	0.051	0.142

Key: SD: standard deviation: ICC; intraclass correlation coefficient; SEM: standard error measurement; N: newton, m: metre; kg: kilogram.

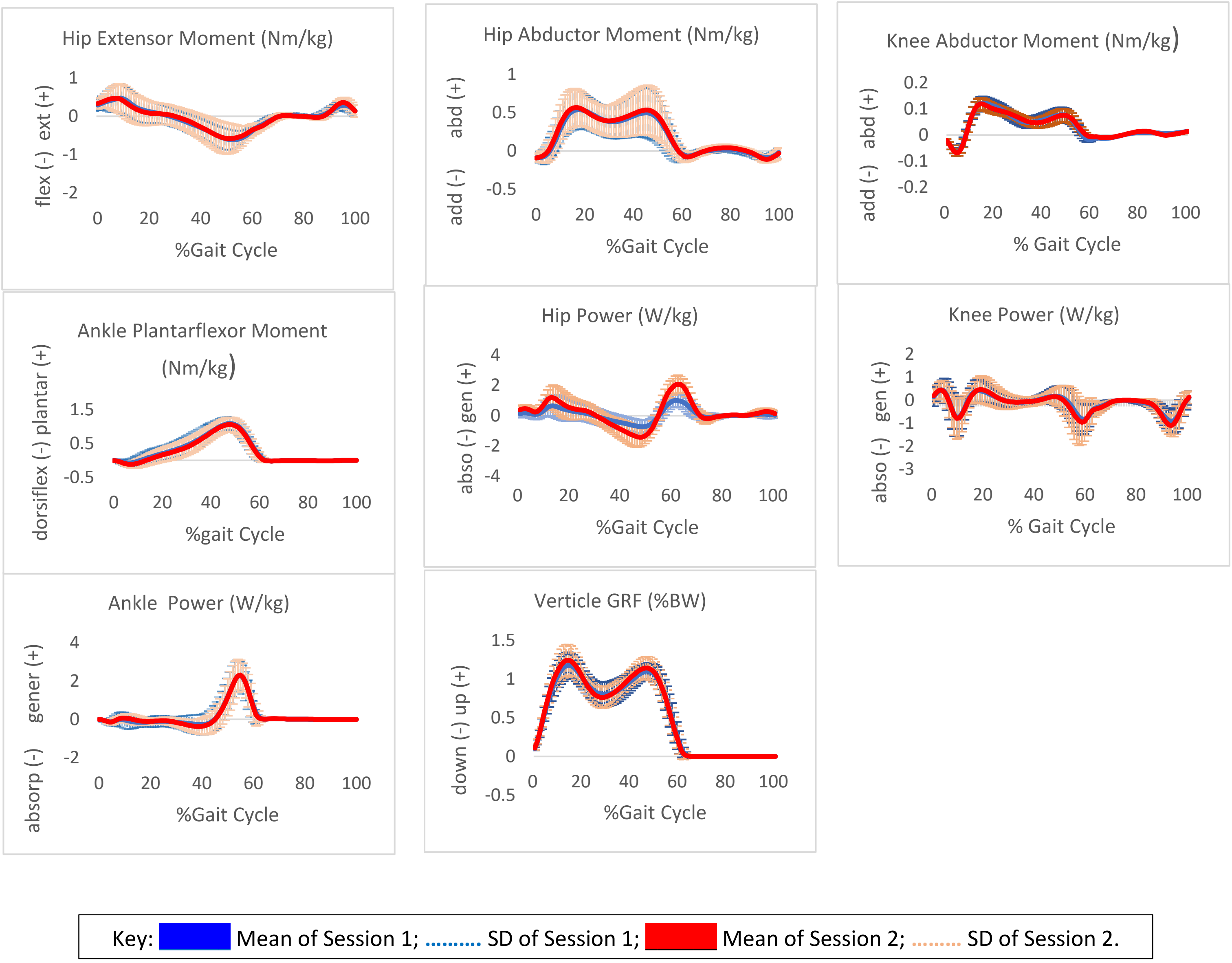


Figure 18: Reliability of kinetic walking data

4.10.8 Discussion

The reliability of placing markers in the static position and walking parameters (temporospatial, kinematic and kinetic parameters) indicates that most of the placing markers position and walking parameters had an excellent repeatability value between sessions. The following paragraph will discuss the result of this current study with walking literature.

Four studies have evaluated the reliability of control group walking parameters. Stolze et al. (1998) investigated the temporospatial reliability in two different sessions among 12 controls. They found that the ICC value for temporospatial parameters varied between slight and substantial (0.3 < ICC < 0.74). They conclude that young children demonstrate higher variability in temporospatial parameters than adults. McSweeney et al. (2020) evaluated the reliability of 17 children walking on an instrumented treadmill between trials in a single session. They found that the ICC value for temporospatial variables and vertical GRF was excellent (ICC > 0.9). Gorton et al. (1997) evaluated the reliability of kinematic walking parameters for 50 children in three sessions. They found the ICC value for all kinematic variables was substantial to excellent (ICC > 0.7). Steinwender et al. (2000) investigated kinematic and kinetic walking parameters among 20 controls in three sessions. They found that the reliability of kinematic parameters was excellent for hip, knee and ankle in the sagittal plane, while the pelvis showed slight repeatability. The frontal kinematic parameters demonstrated substantial to excellent reliability for hip, pelvis and ankle, while the knee had moderate repeatability. The kinematic parameters in the transverse plane only demonstrated excellent reliability for the pelvis, with moderate to slight reliability for the hip and foot. However, the kinetic parameters in Steinwender et al. (2000) demonstrated better reliability, with substantial to excellent reliability.

The results for temporospatial parameters in this current study are better than those in Stoles et al. (1998) and similar to those in McSweeney et al. (2020). Kinematic parameters demonstrated much better reliability in the current study than in Steinwender et al. (2000) and are consistent with Gorton et al. (1997), except for ankle dorsi/plantarflexion, which had moderate reliability. Moreover, the reliability of kinetic variables in this study was similar to Gorton et al. (1997), Steinwender et al. (2000) and McSweeney et al. (2020) studies that showed excellent reliability. However, only hip and knee power parameters in this current study demonstrated substantial and moderate repeatability, unlike Gorton et al. (1997), Steinwender et al. (2000) and McSweeney et al. (2020) studies. This difference in hip and knee power parameters may relate to methodological differences between the current study and prior studies. First, the age is higher in the literature than in the current study. Gorton et al. (1997) and Steinwender et al. (2000) studied children aged between 5 and 16 years, and the mean age in McSweeney et al.'s (2020) study was 11 years, while the children in the current study were between 6 and 12 years of age, with a mean age of 7 years. Gorton et al. (1997) noticed that variability was higher in young children than in older children. Second, both Gorton et al. (1997) and Steinwender et al. (2000) explored reliability over three sessions, while the current study involved only two sessions. More sessions might reduce gait variability as children become familiar with walking in the gait lab. Third, McSweeney et al. (2020) examined reliability between trials in one session and used an instrumented treadmill to measure vertical GRF. This differs from the current study method; it is known that walking on a treadmill is different from overground walking (Van der Krogt et al. 2014). Tesio et al. (2017) report that the instrumented treadmill fixed the subjects' speed, leading to higher repeatability of walking parameters. Moreover, both Oudenhoven et al. (2019) and Van der Krogt et al. (2015) evaluated kinetic data among heathy children using instrumented treadmills and overground walking. They found the kinetic data differed between the treadmill and overground walking due to a fixed walking speed that led to less gait variability; they suggest that the kinetic data for treadmill and overground walking cannot be compared.

4.10.9 Conclusion

This intra-rater reliability study demonstrated excellent reliability on placing markers and most walking parameters among typically developing children between two sessions. This high-reliability result may be related to rigorous methods that have been used in this reliability study using Baker (2006) and Derrick et al. (2020) recommendations. Therefore, the result of this study may provide information on the quality of movement analysis before collecting biomechanical data from non-operative children with Perthes.

4.11 Questionnaires

The questionnaires section discusses the physical activity level, quality of life and how non-operative children with Perthes disease and their parents manage physiotherapy treatment.

4.11.1 Physical activity and quality of life questionnaires

Information on physical activity level and quality of life might provide useful knowledge about how children with Perthes feel and act compared to typically developing children. In the following paragraphs, the physical activity and quality of life questionnaires will be explained.

First, the level of physical activity was checked using the Physical Activity Questionnaire for children (PAQ-C) (appendix xi). This questionnaire was developed to evaluate general physical activity levels among children aged between 6 and 12 years. The PAQ-C requests answers for the last seven days, asking children to select the frequency of participation for a list of activities on the scale: “no”, 1–2 times (in the week), 3–4 times, 5–6 times, and 7 times or more. In addition, there are questions about physical activity in physical exercise lessons, leisure time activities, activities at school, activities after school and “the last weekend”. The aim is to evaluate habitual moderate to vigorous physical activity in child populations (Biddle et al. 2011).

This physical activity questionnaire (PAQ-C) has good reliability and validity value. Janz et al. (2008) examined the validity and reliability of two versions of a common seven-day self-report physical activity questionnaire with a control group (of 210) aged between 11 and 13 years. They found that both versions – PAQ-C and the Physical Activity Questionnaire for Adolescents (PAQ-A) – showed good internal consistency (ICC=0.78) and acceptable validity value (r=0.42). In addition, Voss et al. (2017) assessed the validity and reliability of both the PAQ-C and PAQ-A on 84 children aged between 10 and 16 years old with congenital heart disease conditions of different severities. The results show that the validity was (r=0.55) and reliability was (ICC =0.73) of the PAQ-C and PAC-A with this group were similar to or even stronger than previous control group studies in the literature. Therefore, Voss et al. (2017) recommend that the PAQ questionnaires can be used to estimate general levels of physical activity among children and adolescents with congenital heart disease.

Secondly, quality of life was evaluated using the KIDSCREEN questionnaire (appendix xii). The KIDSCREEN questionnaire aims to identify children who might be at risk because of health problems and can help in determining the negative effects of a certain disease or disability. Checking the health-related quality of life (HRQOL) of children can also assist in predicting hidden morbidity and healthcare requirements, which might not be identified using traditional medical regimes. Two long versions of the KIDSCREEN questionnaire show high reliability and good validity (Hyland 1992; Testa and Simonson 1996). However, there is also a short version of the KIDSCREEN questionnaire called KIDSCREEN-10 score. This short version of KIDSCREEN has certain advantages; for example, it is easy to administer, its results are easy to interpret, and it has good reliability and validity. Furthermore, Ravens-Sieberer et al. (2010) evaluated the criterion and construct validity and test-retest reliability of the KIDSCREEN-10 questionnaire. They included 22,830 European children and adolescents aged between 8 and 18 and their parents (n = 16,237). The results demonstrate that KIDSCREEN-10 provides a valid (r=0.43 to 0.63) and reliable measure (ICC=0.70) of quality of life among the child population. Because of the advantages discussed above, this project used the KIDSCREEN-10 questionnaire.

The KIDSCREEN-10 score contains 10 items. Each item is answered on a five-point response scale. The item statements are: (1) Have you felt fit and well?, (2) Have you felt full of energy?, (3) Have you felt sad?, (4) Have you felt lonely?, (5) Have you had enough time for yourself?, (6) Have you been able to do the things that you want to do in your free time?, (7) Have your parent(s) treated you fairly?, (8) Have you had fun with your friends?, (9) Have you got on well at school? and (10) Have you been able to pay attention? Answer options for items 1 and 9 are: “not at all”, “slightly”, “moderately”, “very” and “extremely”; for all other items the options are “never”, “seldom”, “quite often”, “very often” and “always”. Items 1 and 2 explore the child’s level of physical activity, energy and fitness. Items 3 and 4 cover how much the child experiences depressive moods and emotions and stressful feelings. Items 5 and 6 ask about the child’s opportunities to structure and enjoy his/her social and leisure time and participation in social activities. Item 7 explores the quality of the interaction between child and parent(s)/carer(s) and the child’s feelings towards them. Item 8 examines the nature of the child’s relationships with other children. Finally, items 9 and 10 explore the child’s perception of his/her cognitive capacity and satisfaction with school performance. A low score indicates a poor HRQOL, and a high score is indicative of a better HRQOL.

4.11.1.1 Summary of questionnaires

These two questionnaires have good reliability and validity value. Moreover, they are essential to obtain comparable data on health-related physical activity and quality of life in order to identify any confounding factors that might occur due to lack of general physical activity when performing functional activities.

4.11.2 Managing physiotherapy treatment questionnaire

Understanding how children and parents manage physiotherapy treatment is crucial for increasing the body of knowledge on Perthes disease and allowing physiotherapists to create optimal rehabilitation programmes for patients with Perthes. This questionnaire will help in the interpretation and justification of the findings from the functional activity outcome measures. Given the lack of a questionnaire that evaluates the management of physiotherapy treatment with children with Perthes and families, there is a strong requirement to develop questions that children with Perthes and their parents should answer. The researcher developed a questionnaire called “Managing of physiotherapy treatment with children with Perthes and their families” (appendix xiii). This questionnaire aims to identify how children and families apply physiotherapy recommendations in their lives and how they live with their impairments. This questionnaire used the Perthes literature to help design the Managing of physiotherapy treatment with children with Perthes and their families questionnaire. For example, Leo et al. (2019) interviewed both children with Perthes and their families to investigate the different situations of daily life on both good and bad days. This questionnaire developed by Leo et al. (2019) contained questions related to the social, physical, and emotional impact of Perthes’ disease, such as pain, the impact of the disease on social relationships, and its influence on daily life activities. Palmen et al. (2014) reported that children with Perthes received behavioural advice to reduce certain physical activities that may generate peak impact loads for the hip joint, for example, running and jumping. However, the interview questions in Leo et al. (2019) study did not investigate which daily activities may cause such great pain, which kind of activities doctors suggest not to do, and how children with Perthes manage the clinical provider advice?. Therefore, there is a need to conduct the Managing of physiotherapy treatment with children with Perthes and their families questionnaire to understand how children with Perthes and their families deal with clinical provider advice.

For any questionnaire, a validity test should be performed (Taherdoost 2016). The validity test shows how well the collected data covers the actual area of investigation (Ghauri and Gronhauge 2005). Validity is defined as the extent to which an idea is accurately evaluated in a qualitative study (Heale and Twycross 2015); in other words, validity means measuring what is intended to be measured (Taherdoost 2016). There are three main types of questionnaire validity: content, construct and criterion validity. First, content validity is about whether the instrument adequately addresses all the elements it should with respect to the variable components. One subcategory of content validity is face validity, which requires experts to give their opinions and suggestions about whether an instrument measures the concept. Second, construct validity is the ability to draw inferences regarding the concept being evaluated. The last type of validity is criterion validity, which looks at to what extent a research instrument tool is relevant to other instruments that evaluate the same variables (Heale and Twycross 2015).

As this PhD study was time-constrained, face validity evaluation, relying on experts' opinions, was conducted to test the clarity and understandability of each question. Evaluation of face validity for this questionnaire was achieved via four physiotherapists who are experts in designing questionnaires and dealing with children. The managing physiotherapy treatment questionnaire employed a closed-questions design to obtain quantitative data. Closed-ended questions were designed to obtain information quickly and clearly and cover a large amount of knowledge on how children with Perthes and their parents manage physiotherapy treatment (Lewis 1994). A high degree of dependability was considered in the questionnaire design in order to avoid leading or controversial questions (Lewis 1994).

In designing a questionnaire for children, it is important to consider that children in the early stages of development between 6 and 12 years usually have limited capacity in reading. They might struggle to read skilfully and might misunderstand or miss the intended answer. Evaluation of children was done using a questionnaire with smiley faces and pictures as measurement scales in order to manage the reading issue. In medical settings, smiley-face scales are widely used for evaluating pain among child populations. Buchanan (2005) reports that some children are not able to give a verbal report of their pain, either because they are immature or because of certain diseases or communication issues. Smiley-face scales are also used to identify and quantify dental anxiety among child populations (Buchanan 2005). The logic and reasons for using smiley faces with children are that this method is easy to administer, easily holds the child's attention, and is simple to score and interpret. Preece et al. (2006) report that if children are to be involved in data collection sessions, regardless of what data collection methods are used (e.g., interviews, questionnaires, observations or other types of study), child-friendly methods are necessary to make them feel at ease. For example, data collection sessions need to rely on pictures (such as smiley faces) for children in pre-reading or early reading stages. Therefore, the researcher used both smiley faces and pictures to make the Managing of physiotherapy treatment with children with Perthes and their families questionnaire easy for children and to hold their attention in a friendly way while they completed the questionnaire.

The questionnaire is divided into four sections, each with a specific purpose:

1 Demographic data (age, gender, region, and history of the disease).
2 Physiotherapy data (number of visits, duration of sessions, length of treatment, treatment programme and pain level and management).
3 Advice (what clinical provider advice was recommended for a patient with Perthes, what activities should be avoided and general recommendations about their lives).
4 Parents' and patients' concerns.

4.11.2.1 Piloting

Four researchers with experience in physiotherapy and creating questionnaires piloted the questionnaire, which evaluates how non-operative patients with Perthes manage physiotherapy treatment. They were asked to comment on the format of the questionnaire and its content, wording, instructions and ease of completion. The questionnaire was revised in response to the feedback received, and amendments were made to the questions as suggested by the experts. Once the questionnaire had been amended, two children piloted it to check the clarity.

The questions that were asked at the pilot stage were suggested by Lewis (1994) for PhD researchers:

1. How long did it take you to complete?
2. Were the instructions clear?
3. Were any of the questions unclear or ambiguous? If so, will you say which and why?
4. Did you object to answering any of the questions?
5. In your opinion, has any major topic been omitted?
6. Was the layout of the questionnaire clear/attractive?
7. Any comments?

4.11.2.3 Results of questionnaire piloting study

The results of questionnaire piloting from the four raters showed that the completion time was approximately ten minutes. The raters agreed that the instructions and questions were clear; one rater mentioned some instructions and questions that were not clear. No raters objected to answering any of the questions. The raters made some suggestions for inclusion in the questionnaire. One rater suggested asking directly: What has the physiotherapist asked you to do? Do you like doing what the physiotherapist said? Do you find anything difficult to do? Why? This suggestion was applied to the questionnaire. Another rater suggested adding hydrotherapy and swimming under pain relief. Hydrotherapy was included in the questionnaire, but swimming was not relevant because the questionnaire asked about relieving pain at home. One rater suggested omitting the parent’s and child's distinct goals for physiotherapy as they would be the same. In fact, the purpose of asking parent and child the same question was to see whether their physiotherapy goals were similar or not. All four raters reported that the layout of the questionnaire was clear and attractive. There was no further comment on the questionnaire and the relevant suggestions were applied. The two children who piloted the questionnaire completed it without comment (Table 20).

Table 20: Results of questionnaire piloting study

Questions	Rater 1	Rater 2	Rater 3	Rater 4
1) How long did it take you to complete?	Less than 10 mins	Approximately 10 mins	Approximately 15 mins	7 to10 mins
2) Were the instructions clear?	Yes	Yes	A couple of the instructions/questions (2 and 3) were a bit difficult to understand.	Yes
3) Were any of the questions unclear or ambiguous? If so, will you say which and why?	No, I found all questions clear.	No	A couple of the instructions/questions (2 and 3) were a bit difficult to understand.	No
4) Did you object to answering any of the questions?	No	No	No, I did not object to answering any questions. They all seemed very relevant and not intrusive at all.	No
5) In your opinion, has any major topic been omitted?	Perhaps ask directly. What has the physiotherapist asked you to do? Do you like doing what the physiotherapist said? Do you find anything difficult to do? Why?	Include hydrotherapy and swimming as pain relief.	The only thing I could think [of] that may have been omitted was the parents/ child's goals for physiotherapy and [whether] they were the same as the physiotherapist's goals.	No
6) Was the layout of the questionnaire clear/attractive?	Yes – pictures are good and encouraging.	Yes	Yes	Very clear
7) Any comments?	No	No	No	No

4.12 Statistical considerations

4.12.1 Normality testing and homogeneity of variance

To satisfy the assumptions for parametric testing, data must be normally distributed between groups (Portney and Watkins 2008; Field 2009). Before commencing statistical analysis, all study results were evaluated using the Shapiro-Wilk (S-W) test for normality. Significance for normality was set at $p<0.05$, with all analyses below this value assumed to be normally distributed to support the use of a parametric test. Where a minority of variables within a data set reported S-W values that narrowly missed significance at the $p<0.05$ level, residual plots and histograms of unstandardised residuals for each variable were visually inspected as a secondary check for normality. If these appeared to be normally distributed, and the S-W test only narrowly missed the significance, the variable was accepted as normally distributed. Full details are documented in appendix xxiii.

4.12.2 Statistical analysis

All statistical analyses were conducted using SPSS. To ensure baseline subject characteristics were not confounding variables in the results, age, height, weight and BMI, lower limb ROM, lower limb muscle strength, knee and ankle width, and data from the three functional activities and the questionnaires (PAQ-C and KIDSCREEN) were evaluated between groups using one way ANOVA, provided the requirements of parametric testing were achieved. Where these assumptions were not met, the non-parametric Kruskal-Wallis test was used. Furthermore, if the one way ANOVA or Kruskal-Wallis tests showed a significant difference, then a post hoc test was conducted to determine pairwise differences between groups. Effect sizes were determined using the partial eta squared, for which 0.01, 0.06 and 0.14 are defined as small, medium and large, respectively (Cohen 1992; Richardson 2011). The effect size will be presnted in the table in **bold** to indicate the large effect. The analysis of the third questionnaire (Managing of physiotherapy treatment with non-operative children with Perthes and their families) was presented in pie charts reporting the frequency.

Chapter Five: Study Two

Evaluation of compensation strategies in functional activities, level of physical activity, quality of life, and management of physiotherapy treatment for non-operative children with Legg-Calve-Perthes disease

5.1 Overview

This chapter commences with a section on the introduction to identify the literature findings and the knowledge gap and present the study's objective. The methods of this study were presented in the previous chapter. The results section presents the demographic data and is followed by two sections, including comparing the three functional activities and the results of questionnaires on level of physical activity, quality of life, and management of physiotherapy treatment. The remainder of the chapter discusses the findings and the conclusion.

5.2 Introduction

Based on the previous systematic review study, children with Perthes demonstrate movement-compensation involving the trunk and lower limb joints in three planes (sagittal, frontal, and transverse) during walking. Although children with Perthes demonstrate obvious signs of gait instability (such as low gait speed, short stride length and prolonged stance time and Trendelenburg’s sign), only one study has investigated postural stability. Postural stability is crucial to the ability of a subject to maintain his/her postural stability while performing functional activities, to prevent injuries and joint fracture. Hailer et al. (2014) found that 52% of 145 children with Perthes experienced severe problems such as soft tissue injury due to joint instability. Karimi and Esrafilian (2013) found that children with Perthes were significantly unstable compared to healthy children in mediolateral (COP) direction during balance activity; they attribute this difference to the weakness of hip muscles surrounding the hip joint. These previous studies may indicate poor postural stability for a high risk of soft tissue injuries and bone fracture among children with Perthes. To investigate postural stability for children with Perthes, the single-leg balance activity is the most challenging task that could provide critical information about how the subject performs to maintain his/her postural stability to prevent the risk of falling. Donath et al. (2016) compared different balance activities, including a double-limb stance on a foam surface with both eyes open and closed, a double-limb stance on firm ground with both eyes open and closed, and a single-limb stance on firm ground with eyes open. They found that standing on a single leg demonstrated significant postural sway compared to other balance tasks. In addition, Mani et al. (2019) suggest evaluating a single-leg balance activity as an essential task to walk independently as it is similar to the single-limb support phase of the gait cycle. The squat activity is another essential functional activity that is frequently performed while doing routine daily activities or as part of an exercise, for example, sit-to-stand and jumping (Eken et al. 2017; Stevens et al. 2018).

Moreover, the Cincinnati guideline (Children and Medical Center 2011) recommends considering the squat task for children with Perthes as a strengthening exercise for hip muscle weakness to prevent pelvic drop during the single stance phase of walking. Children with Perthes experience movement compensation in walking (as presented in the previous systematic review chapter). It is assumed that compensation also occurs in single-leg balance and squat activities, which needs to be proved. Therefore, this study aims to investigate gait stability in children with Perthes and explore movement-compensation during single-leg balance and squat activities to identify possible strategies to overcome pain, muscle weakness, and the abnormal shape of the Perthes hip joint. It is valuable information for clinical providers, which might assist in setting goals for rehabilitation management based on patient findings.

To understand the effect of Perthes disease on the lives of children and their parents, specific information should be considered: for example, physical activity level, quality of life, and how children with Perthes and their parents manage physiotherapy treatment. It is recommended that the physiotherapist obtain several types of information: not only that which is relevant to diagnosis, prognosis, and biomedical knowledge of the body but also information on the experience of living with impairments and managing physiotherapy treatment (Shaw et al. 2012). There is little work investigating the effect of Perthes disease on the lives of children and parents. However, there is no study linking movement compensation in functional activities and level of physical activity to quality of life for children with Perthes. Therefore, evaluating how non-operative children with Perthes compensate in their movement during functional activities, their level of physical activity, their quality of life, and how they and their parents manage physiotherapy treatment may provide essential knowledge to build a good understanding of the effects of the disease.

5.2.1 Research questions and hypotheses

There are four objectives for this second study. These include a) is to investigate movement-compensation strategies during walking, single-leg balance, and squat activities, b) to evaluate the level of physical activity and the quality of life of children with Perthes, c) how non-operative Perthes children and their parents manage physiotherapy treatment, d) to investigate the link between movement-compensation during functional activities and level of physical activity and the quality of life for children with Perthes.

Q1: What are the movement-compensation developed by non-operative children with Perthes during walking, single leg balance, and squat activities compared to the control group?
H1: The non-operative children with Perthes compensate their movement during three functional activities compared to the control group.

Q2: What are the differences between Perthes and the control groups in the physical activity level and the quality of life?
H2: The non-operative children with Perthes have lower physical activity levels and poor quality of life than the control group.

Q3: How do non-operative children with Perthes and their families manage the physiotherapy treatment?

Q4: What are the link between movement-compensation during three functional activities, the physical activity level and the quality of life for children with Perthes.

5.3 Methods

A full description of the method for this study was provided in the method chapter (see chapter four).

5.4 Results

The results section divides into four subsections. The first subsection gives the statistical analysis of the parameters for the functional activities and questionnaires in relation to the normal distribution of the results. The following presents comparisons between the control and Perthes groups in functional activities (walking, single-leg balance, and squat) to identify compensation mechanisms. The same subsection gives demographic data (average age, height, body mass, leg length, Trendelenburg’s sign and Thomas test) for both groups and makes comparisons by considering mean and standard deviation and presenting figures for functional activities. The third subsection includes the results of the physical activity level and quality of life questionnaires for both control and Perthes groups and the managing physiotherapy treatment questionnaire results. The final subsection summarises and links the results for functional activities for both groups to those for physical activity and quality of life questionnaires.

5.4.1 Statistical analysis

Table 21 outlines the statistical test chosen for each parameter in relation to the normal distribution of the results, as discussed in the methodology section. Based on the literature search, if one parameter is found not to be normally distributed, then the non-parametric test is used for the rest of the parameters in the same section. For example, if one aspect of the demographic data is found not to be normally distributed, then the non-parametric test is applied for all demographic parameters. The normality test was performed using the Shapiro-Wilk test, and the significance level was set at p<0.05.

Table 21: Choice of statistical test based on the normal distribution of data

Normal distribution	**Between-group differences (control and Perthes groups)**	
	Normally distributed	**Not normally distributed**
Outcomes	Muscle strength test	Demographic parameters Passive range of motion Walking parameters Single-leg balance parameters Squat parameters Physical activity questionnaire (PAQ-C). Health-related quality of life questionnaire (KIDSCREEN-10)
Test and significance level	One way ANOVA (p<0.05)	Kruskal-Wallis (p<0.05)

5.4.2 Comparison between control and Perthes data

The comparison between control and Perthes groups considers the right leg in the control group and both legs in the Perthes group (affected and non-affected sides). This section begins with four subsections that compare demographic data, followed by comparing walking, balance, and squat activities between control and Perthes groups. The parametric one-way ANOVA is used in the muscle test as a parametric test, while the rest use the Kruskal-Wallis test as a non-parametric test.

5.4.3 Demographic data

5.4.3a Population properties

Table 22 shows the number of participants: 15 children in the control group, nine boys and six girls, 9 Perthes children, six boys, and three girls. There was no statistically significant difference between control and Perthes groups in any parameter except BMI (p<0.05), higher in the Perthes group. In the Perthes group, leg length was similar on affected (involved) and non-affected (uninvolved) sides. In two children with Perthes, Trendelenburg's sign was observed, and five children with Perthes experienced pain in the groin region of the hip when the Thomas test was applied.

Table 22: Population properties compared between control and Perthes groups

	Control	Perthes	P	E
	Mean (± SD)	Mean (± SD)		
Number of subjects	Fifteen children: Nine boys and six girls	Nine children: Six boys and three girls		
Age (years)	7.9 (± 1.82)	7.9 (± 1.54)	0.770	
Height (m)	1.25 (± 0.11)	1.26 (± 0.09)	0.861	
Body mass (kg)	25.59 (± 6.22)	29.44 (± 4.99)	0.174	
Body mass index (BMI)	16.11 (± 1.91)	18.43 (± 2.12)	**0.008**	**0.28**
Leg length (m)	0.69 (± 0.06)	0.67 (± 0.05)	0.770	
Trendelenburg's sign	0	Two children had a positive sign		
Thomas test	0	Five children had a positive sign		

Key: **Bold** indicates significant value; SD: standard deviation; m: metre; kg: kilogram; s: second; p: significant difference; E: effect size

5.4.3b Children with Perthes's characteristics

The Classification Instrument in Perthes (CLIPer) was used to determine the severity of Perthes disease for each Perthes participant. Severity is defined by the total CLIPer score, as follows: 0–5 = mild involvement; 6–13 = moderate involvement; and 14–24 = severe involvement. Based on the CLIPer, seven children with Perthes were in the mild stage, and two were in the moderate stage. One child reported a pain level between 4 and 6 based on the Wong-baker pain scale. Both ROM and muscle strength were affected in three children with Perthes: ROM and muscle strength on the involved Perthes side were approximately less by 50% to 75% of those on the uninvolved side. The balance activity was the highest impact in five children, who displayed approximately 25% to 50% difference between involved and uninvolved sides. In addition, gait was affected in two children with Perthes. The following table highlights the results of the CLIPer (Table 23).

Table 23: Classification instrument in Perthes (CLIPer)

Domains of assessment	Description	Score	S1	S2	S3	S4	S5	S6	S7	S8	S9
Pain with ADLs	7 to 10 out of 10	4	0	2	0	0	0	0	0	0	0
	4 to 6 out of 10	2									
	0 to 3 out of 10	0									
Hip ROM	Less than 50% of uninvolved side for the majority of directions	6	0	3	0	3	0	0	0	0	3
	50% to 75% of the uninvolved side for the majority of directions	3									
	76 to 100% of the uninvolved side for the majority of directions	0									
Hip strength	Less than 50% of uninvolved side for the majority of muscle group	6	0	0	0	0	3	3	3	0	0
	50% to 75% of the uninvolved side for the majority of the muscle group	3									
	76% to 100% of the uninvolved side for the majority of the muscle group	0									
Balance	Less than 50% of time on uninvolved side with eyes open	6	3	0	3	3	2	0	0	0	2
	50% to 75% of the time on the uninvolved side with eyes open	3									
	76% to 100% of the time on the uninvolved side with eyes open	0									
Gait	NWB and uses an AD and without AD displays excessive gait deficit with decreased efficiency.	4	0	2	0	2	0	0	0	0	0
	No AD and displays excessive deficits without decrease in efficiency. Uses steps to pattern on stairs.	2									
	Non-painful limp, able to perform reciprocal pattern on stairs.	0									
Total score			3	7	3	8	5	3	3	0	5

Key: ADLs: activities of daily living; ROM: range of motion; S: Perthes subject; NWB: non-weight bearing; AD: assistive device.

5.4.3c Passive range of motion

Table 24 presents a comparison between passive ROM for the control and Perthes groups. There is no statically significant difference between Perthes legs and control groups in passive joint range of motion (p>0.05).

Table 24: Comparison between control and Perthes groups in passive range of motion

Parameters	**Control** **Mean (± SD)**	**Perthes** **Mean (± SD)**		**P**
		Affected	**Non-affected**	
Hip flexion°	129.333 (± 9.302)	127.67 (± 10.012)	132.56 (± 14.39)	0.439
Hip extension°	15.067 (± 4.773)	12.78 (± 3.49)	12.67 (± 2.35)	0.160
Hip abduction°	41.267 (± 3.75)	42.33 (± 2.65)	43.11 (± 5.33)	0.516
Hip adduction°	22.87 (± 3.58)	20.11 (± 4.05)	21.56 (± 2.24)	0.475
Hip internal rotation°	37.6 (± 6.434)	32.56 (± 8.16)	38.78 (± 7.17)	0.238
Hip external rotation°	44.2 (± 6.7)	39.33 (± 5.24)	39.78 (± 7.66)	0.129
Knee flexion°	137.133 (± 11.526)	138 (± 27.76)	135.56 (± 26.88)	0.104
Knee extension°	3.13 (± 1.14)	3.78 (± 1.64)	3.33 (± 2.24)	0.481
Ankle dorsiflexion°	32.8 (± 8.65)	30.89 (± 8.42)	30.89 (± 6.29)	0.953
Ankle plantarflexion°	50.13 (± 7.69)	47.56 (± 7.5)	49.78 (± 6.16)	0.782

Key: **Bold** indicates significant value; SD: standard deviation; P1: p-value for affected (Perthes) side compared to non-affected (Perthes) side; P2: p-value for control compared to affected (Perthes) side; P3: p-value for normal compared to non-affected (Perthes) side.

5.4.3d Muscle strength test

Table 25 shows no statistically significant difference between Perthes legs and control groups in the lower limb muscle strength test (p>0.05).

Table 25: Muscle strength test

Parameters	**Control** **Mean (± SD)**	**Perthes** **Mean (± SD)**		**P**
		Affected	**Non-affected**	
Hip flexion (N/Kg)	3.52 (± 0.83)	2.9 (± 0.701)	3.06 (± 0.492)	0.097
Hip extension (N/Kg)	2.42 (± 0.61)	2.27 (± 0.596)	2.28 (± 0.362)	0.756
Hip abduction (N/Kg)	2.98 (± 0.72)	2.69 (± 0.563)	2.97 (± 0.473)	0.974
Hip adduction (N/Kg)	3.22 (± 0.83)	3.15 (± 0.921)	3.15 (± 1.006)	0.549
Hip internal rotation (N/Kg)	2.14 (± 0.48)	1.93 (± 0.44)	2.13 (± 0.465)	0.631
Hip external rotation (N/Kg)	2.20 (± 0.52)	1.93 (± 0.16)	2.13 (± 0.461)	0.661
Knee flexion (N/Kg)	2.90 (± 0.56)	2.74 (± 0.536)	2.81 (± 0.477)	0.858
Knee extension (N/Kg)	3.70 (± 0.80)	3.44 (± 0.749)	3.65 (± 0.778)	0.457
Ankle dorsiflexion (N/Kg)	2.60 (± 0.59)	2.36 (± 0.373)	2.55 (± 0.474)	0.644
Ankle plantarflexion (N/Kg)	3.16 (± 0.78)	2.94 (± 0.411)	3.03 (± 0.758)	0.771

Key: **Bold** indicates significant value; SD: standard deviation; P1: p-value for the affected (Perthes) side compared to the non-affected (Perthes) side; P2: p-value for control compared to affected (Perthes) side; P3: p-value for normal compared to non-affected (Perthes) side.

5.4.4 Walking activity parameters

This section compares temporospatial, kinematic, and kinetic parameters during walking between the control group and the Perthes group (including affected and non-affected legs) in three planes (sagittal, frontal, and transverse).

5.4.4.1 Temporospatial walking parameters

Table 26 demonstrates no statistically significant difference between Perthes and control groups in temporospatial walking parameters, except in stride width, which was lower in the Perthes group (p<0.05) with a large effect size (0.177).

Table 26: Temporospatial parameters

	Control Mean (± SD)	**Perthes Mean (± SD)**		**P0**		**E0**
		Affected	**Non-affected**			
Speed (m/s)	1.182 (± 0.14)	1.176 (± 0.098)		0.976		
Stride width (m)	0.095 (± 0.016)	0.083 (± 0.014)		**0.041**		**0.177**
Stride length (m)	1.113 (± 0.177)	1.109 (± 0.058)		0.599		
Cadence (steps/min)	125.603 (± 11.51)	126.795 (± 7.967)		0.953		
				P1	P2	P3
Step length (m)	0.551 (± 0.053)	0.545 (± 0.039)	0.563 (± 0.036)	0.297	0.482	0.599
Stance phase (s)	0.575 (± 0.058)	0.583 (± 0.034)	0.591 (± 0.038)	0.666	0.77	0.519
Swing phase (s)	0.368 (± 0.052)	0.362 (± 0.029)	0.362 (± 0.035)	0.863	0.77	0.815

Key: **Bold** indicates significant value; SD: standard deviation; P0: p-value for control group compared to Perthes group. P1: p-value for affected side compared to non-affected (Perthes) side; P2: p-value for control compared to affected (Perthes) side; P3: p-value for normal compared to unaffected (Perthes) side; E0: effect size for control group compared to Perthes group; E1: effect size for affected side compared to non-affected (Perthes) side; E2: effect size for control compared to affected (Perthes) side; E3: effect size for the control compared to unaffected (Perthes) side; m: metre; s: second.

5.4.4.2 Walking activity parameters: Sagittal plane

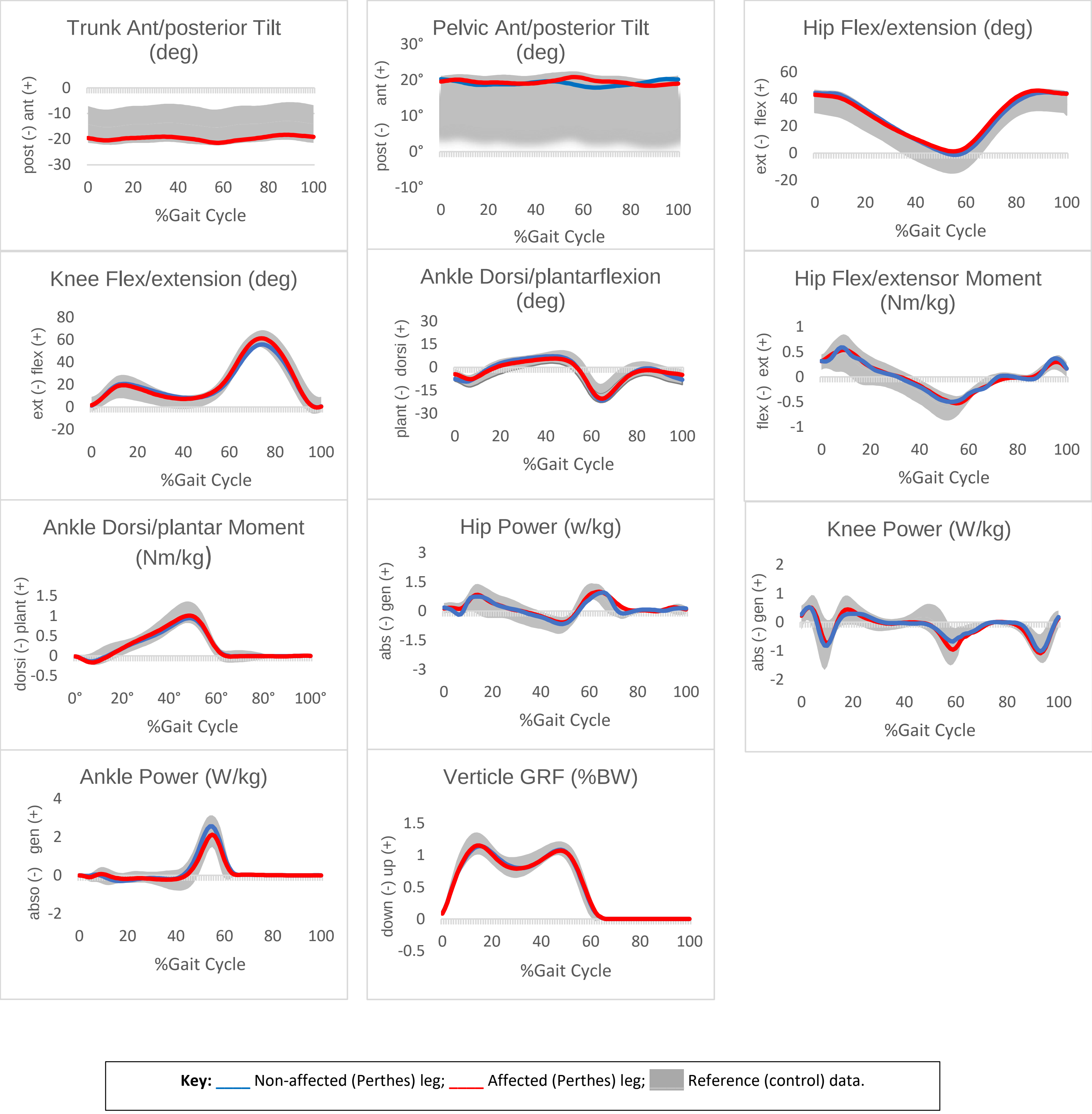
Table 27 and figure 19 present the analysis of the kinematic parameters in the sagittal plane. The deviations are mainly at the hip joint. The trunk and pelvis movement revealed no statistically significant difference between Perthes and control groups (p>0.05). The Perthes group displayed a statistically significant difference between both legs at the hip joint and control in minimum hip flexion. The affected Perthes side showed hip flexion throughout the whole gait cycle, with a statistically significant difference (p=0.006) compared to the control group by approximately 7° and with a large effect size (0.333). Moreover, the non-affected Perthes leg demonstrated less hip extension by approximately 6° difference than the control group, and this was a statistically significant difference (p=0.03) with a large effect size (0.214). At the knee and ankle joints level, there was no statistically significant difference in ROM between the control and both Perthes legs (p>0.05).

The kinetic data showed no statistically significant difference between the control and Perthes groups in all parameters (p>0.05). There is no statistically significant difference between Perthes legs in all kinetic parameters (p>0.05).

Table 27: Walking activity parameters (Sagittal plane)

Parameters		Control Mean (± SD)	Perthes Mean (± SD)		P0				
			Affected	Non-affected					
Kinematic parameters									
Trunk	Maximum anterior tilt (°)	-12.879 (±7.498)	-18.306 (±11.926)		0.601				
	Minimum anterior tilt (°)	-15.459 (±6.843)	-21.430 (±10.605)		0.357				
	ROM (°)	2.580 (±0.655)	3.124 (±1.321)		0.601				
					P1	**P2**	**E2**	**P3**	**E3**
Pelvis	Maximum anterior tilt (°)	15.086 (±7.697)	20.821 (±12.066)	20.262 (±9.394)	0.931	0.164		0.164	
	Minimum anterior tilt (°)	12.763 (±6.841)	18.395 (±10.588)	17.872 (±7.649)	0.931	0.164		0.144	
	ROM (°)	2.324 (±0.857)	2.426 (±1.479)	2.389 (±1.746)	0.931	0.292		0.292	
Hip	Maximum flexion (°)	39.212 (±9.255)	46.205 (±11.647)	44.910 (±11.402)	1.00	0.110		0.164	
	Minimum flexion (°)	-7.304 (±6.792)	1.317 (±8.244)	-1.282 (±8.420)	0.546	**0.006**	**0.333**	**0.030**	**0.214**
	ROM (°)	46.515 (±2.464)	44.889 (±3.404)	46.192 (±2.983)	0.387	0.431		0.794	
Knee	Maximum flexion (°)	61.031 (±13.258)	61.269 (±11.021)	55.822 (±19.667)	0.863	0.695		0.292	
	Minimum flexion (°)	1.790 (±5.784)	-0.438 (±4.638)	-0.269 (±5.058)	0.931	0.357		0.324	
	ROM (°)	59.241 (±7.474)	61.708 (±6.383)	56.090 (±14.609)	0.489	0.292		0.126	
Ankle	Maximum dorsiflexion (°)	6.795 (±7.41)	5.687 (±7.668)	7.200 (±9.726)	0.863	0.164		0.601	
	Minimum dorsiflexion (°)	-16.807 (±3.557)	-20.335 (±3.559)	-21.534 (±3.191)	0.730	0.292		0.164	
	ROM (°)	23.602 (±3.854)	26.023 (±4.109)	28.734 (±6.535)	0.340	0.556		0.186	
Kinetic parameters					**P1**	**P2**		**P3**	
Peak hip extensor moment (Nm/kg)		0.475 (±0.385)	0.540 (±0.371)	0.590 (±0.426)	0.489	0.601		0.324	
Peak ankle plantar flexor moment (Nm/kg)		1.092 (±0.291)	1.005 (±0.248)	0.945 (±0.378)	0.190	0.695		0.357	
Hip power (W/kg)	Generation	1.011 (±0.801)	0.995 (±0.817)	0.957 (±1.012)	0.730	0.845		0.845	
	Absorption	-0.734 (±0.067)	-0.585 (±0.033)	-0.668 (±0.094)	0.222	0.164		0.794	
Knee power (W/kg)	Generation	0.456 (±0.94)	0.515 (±0.855)	0.525 (±1.273)	0.796	0.796		0.647	
	Absorption	-0.916 (±0.032)	-1.082 (±0.067)	-1.011 (±0.027)	0.340	0.896		0.357	
Ankle power (W/kg)	Generation	2.289 (±0.983)	2.123 (±0.938)	2.560 (±1.331)	0.077	0.601		0.110	
	Absorption	-0.274 (±0.002)	-0.227 (±0.002)	-0.300 (±0.003)	0.769	0.845		1.00	
Total power generation		3.756	3.633	4.042					
Total power absorption		-1.924	-1.894	-1.979					
Peak vertical GRF (%BW)		1.178 (±0.211)	1.152 (±0.171)	1.142 (±0.246)	0.796	0.144		0.209	

Key: **Bold** indicates significant value; SD: standard deviation; °: degree; GRF: ground reaction force; N: newton; kg: kilogram; W: watt; P0: p-value for control group compared to Perthes group. P1: p-value for affected side compared to non-affected (Perthes) side; P2: p-value for control compared to affected (Perthes) side; P3: p-value for normal compared to unaffected (Perthes) side; E2: effect size for control compared to affected (Perthes) side; E3: effect size for the control compared to unaffected (Perthes) side.



Trunk Ant/posterior Tilt (deg)

Pelvic Ant/posterior Tilt (deg)

Hip Flex/extension (deg)

Knee Flex/extension (deg)

Ankle Dorsi/plantarflexion (deg)

Hip Flex/extensor Moment (Nm/kg)

Ankle Dorsi/plantar Moment (Nm/kg)

Hip Power (w/kg)

Knee Power (W/kg)

Ankle Power (W/kg)

Verticle GRF (%BW)

Figure 19: Walking data (Sagittal plane)

5.4.4.3 Walking activity parameters: Frontal plane

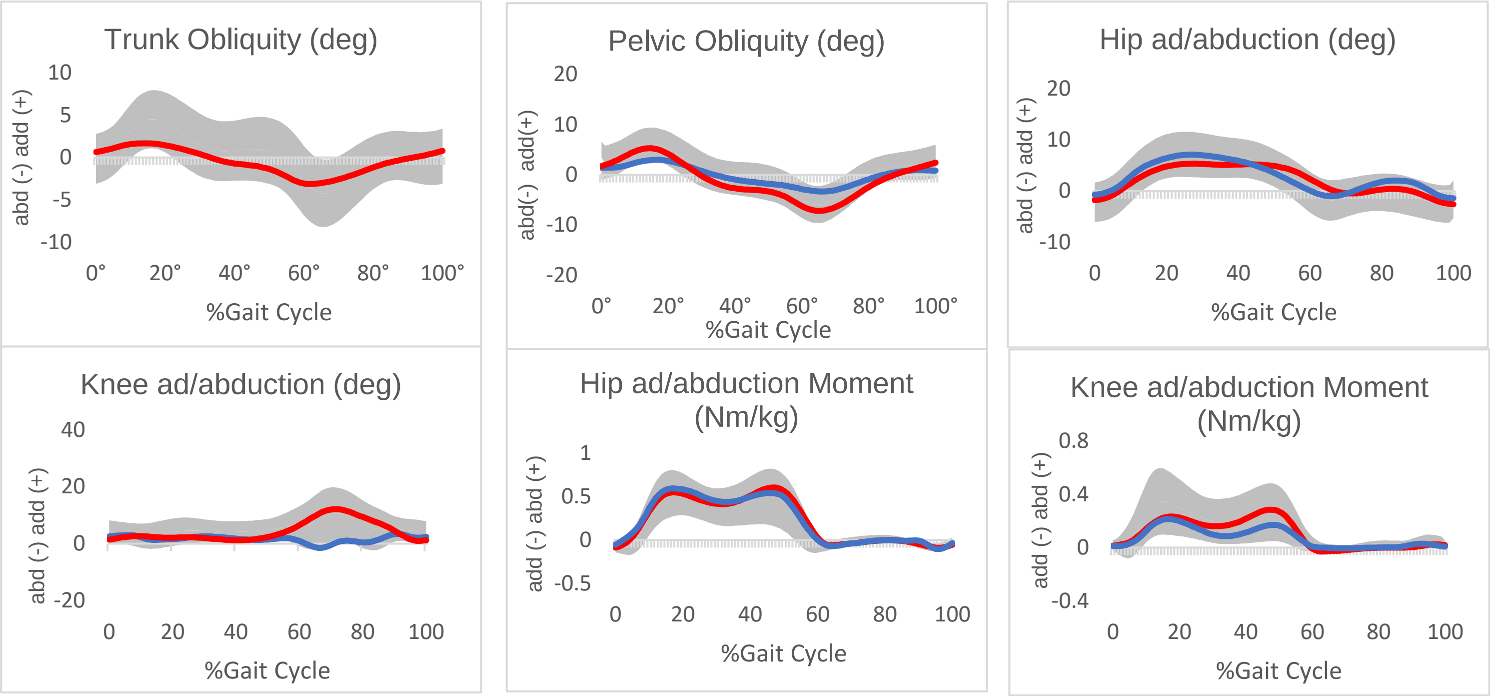
As reported in the Perthes literature, the frontal plane kinematic parameters consider the stance phase to investigate movement compensation. The parameters of the stance phase include the single-limb support (which comprises on average 25% to 35% of the gait cycle) and maximum and minimum adduction and ROM for each joint (trunk, pelvis, hip, and knee). Table 28 and figure 20 present the movement pattern in the frontal plane during the gait cycle.

At single-limb support (on average 25% to 35% of the gait cycle), the control subjects demonstrated trunk lean of 1.611° towards the stance limb in relation to the pelvis, slight pelvic dropped (1.281°) towards the swing limb, and adduction of the hip and knee joints (6.932° and 4.423°, respectively). The affected Perthes leg displayed slight trunk lean towards the stance limb of 0.378°; slight pelvis dropped towards the stance limb (0.111°), hip and knee adduction of 5.262° and 4.529°, respectively. The affected Perthes leg showed a statistically significant difference ($p<0.05$) compared to control as demonstrated slight trunk lean towards the stance limb and less hip adduction by approximately 1.3° and 1.7 °, respectively. The non-affected leg in the Perthes group exhibited a similar movement pattern to controls with no statistically significant difference ($p>0.05$). Regarding ROM, the affected Perthes leg showed no significant difference in trunk, pelvis, hip, and knee joints ($p>0.05$). The non-affected Perthes leg demonstrated a statistically significant difference in the pelvis and knee ROM ($p<0.05$) due to reduced maximum and minimum pelvis and knee adduction by approximately 3° and 7°, respectively. The non-affected Perthes leg showed no statistically significant difference in hip adduction ROM ($p>0.05$). Comparing affected Perthes leg to non-affected Perthes leg, there is a statistically significant difference in pelvis and knee adduction ROM ($p<0.05$) due to less minimum pelvis adduction and maximum knee adduction by approximately 6° and 9°, respectively.

In the kinetic data, hip and knee abductor moment peaks were higher in the Perthes group than the control group by approximately 0.06 and 0.13 Nm/kg, respectively. These differences in hip and knee abductor moment peaks in the Perthes group were significantly higher ($p<0.05$) in the hip abductor moment, while the peak of the knee abductor moment showed no statistically significant difference compared to the control group ($p>0.05$).

<table>
<tr><th colspan="11">Table 28: Walking activity parameters (frontal plane)</th></tr>
<tr><th colspan="2" rowspan="2">Parameters</th><th rowspan="2">Control
Mean (± SD)</th><th colspan="2">Perthes Mean (± SD)</th><th colspan="5" rowspan="2">P0</th><th rowspan="2">E0</th></tr>
<tr><th>Affected</th><th>Non-affected</th></tr>
<tr><td colspan="11">Kinematics parameters</td></tr>
<tr><td rowspan="4">Trunk</td><td>Trunk obliquity in single stance (°)</td><td>1.611 (±3.662)</td><td colspan="2">0.378 (±3.991)</td><td colspan="5">0.003</td><td>0.384</td></tr>
<tr><td>Maximum adduction (°)</td><td>4.508 (±4.101)</td><td colspan="2">1.668 (±6.285)</td><td colspan="5">0.292</td><td></td></tr>
<tr><td>Minimum adduction (°)</td><td>-4.247 (±2.893)</td><td colspan="2">-3.133 (±3.188)</td><td colspan="5">0.512</td><td></td></tr>
<tr><td>ROM (°)</td><td>8.755 (±1.208)</td><td colspan="2">4.801 (±3.097)</td><td colspan="5">0.601</td><td></td></tr>
<tr><td colspan="5"></td><td>P1</td><td>E1</td><td>P2</td><td>E2</td><td>P3</td><td>E3</td></tr>
<tr><td rowspan="4">Pelvis</td><td>Pelvic obliquity in single stance (°)</td><td>1.281 (±3.467)</td><td>-0.111 (±4.146)</td><td>0.795 (±2.989)</td><td>0.340</td><td></td><td>0.082</td><td></td><td>0.512</td><td></td></tr>
<tr><td>Maximum adduction (°)</td><td>6.199 (±3.696)</td><td>4.067 (±4.762)</td><td>2.989 (±4.467)</td><td>0.863</td><td></td><td>0.089</td><td></td><td>0.096</td><td></td></tr>
<tr><td>Minimum adduction (°)</td><td>-5.922 (±2.708)</td><td>-8.416 (±3.319)</td><td>-3.321 (±2.831)</td><td>0.113</td><td></td><td>0.601</td><td></td><td>0.110</td><td></td></tr>
<tr><td>ROM (°)</td><td>12.122 (±0.989)</td><td>12.483 (±1.444)</td><td>6.310 (±1.636)</td><td>0.04</td><td>0.239</td><td>0.556</td><td></td><td>0.014</td><td>0.269</td></tr>
<tr><td rowspan="4">Hip</td><td>Hip adduction in single stance (°)</td><td>6.932 (±4.290)</td><td>5.262 (±4.563)</td><td>6.936 (±4.179)</td><td>0.258</td><td></td><td>0.001</td><td>0.580</td><td>0.948</td><td></td></tr>
<tr><td>Maximum adduction (°)</td><td>7.174 (±4.412)</td><td>5.342 (±6.036)</td><td>7.118 (±5.882)</td><td>0.605</td><td></td><td>0.647</td><td></td><td>0.845</td><td></td></tr>
<tr><td>Minimum adduction (°)</td><td>-2.539 (±3.573)</td><td>-2.580 (±2.550)</td><td>-1.405 (±3.877)</td><td>0.931</td><td></td><td>0.744</td><td></td><td>1.00</td><td></td></tr>
<tr><td>ROM (°)</td><td>9.713 (±0.839)</td><td>7.922 (±3.486)</td><td>8.523 (±2.005)</td><td>0.387</td><td></td><td>0.071</td><td></td><td>0.082</td><td></td></tr>
<tr><td rowspan="4">Knee</td><td>Knee adduction in single stance (°)</td><td>4.423 (±4.111)</td><td>2.311 (±4.303)</td><td>2.397 (±6.378)</td><td>1.00</td><td></td><td>0.431</td><td></td><td>0.845</td><td></td></tr>
<tr><td>Maximum adduction (°)</td><td>10.623 (±9.783)</td><td>12.069 (±10.477)</td><td>3.411 (±23.314)</td><td>0.258</td><td></td><td>0.695</td><td></td><td>0.164</td><td></td></tr>
<tr><td>Minimum adduction (°)</td><td>2.693 (±3.667)</td><td>0.951 (±1.898)</td><td>-1.508 (±4.192)</td><td>0.258</td><td></td><td>0.556</td><td></td><td>0.431</td><td></td></tr>
<tr><td>ROM (°)</td><td>7.930 ± (6.116)</td><td>11.119 (±8.579)</td><td>4.918 (±19.123)</td><td>0.04</td><td>0.239</td><td>0.601</td><td></td><td>0.030</td><td>0.214</td></tr>
<tr><td colspan="11">Kinetic parameters</td></tr>
<tr><td colspan="2">Peak hip abductor moment (Nm/kg)</td><td>0.539 (±0.329)</td><td>0.604 (±0.307)</td><td>0.594 (±0.341)</td><td>0.387</td><td></td><td>0.096</td><td></td><td>0.043</td><td>0.189</td></tr>
<tr><td colspan="2">Peak knee abductor moment (Nm/kg)</td><td>0.123 (±0.029)</td><td>0.284 (±0.345)</td><td>0.214 (±0.313)</td><td>0.340</td><td></td><td>0.186</td><td></td><td>0.556</td><td></td></tr>
</table>

Key: **Bold** indicates significant value; SD: standard deviation; °: degree; N: newton; kg: kilogram; P0: p-value for control group compared to Perthes group. P1: p-value for affected side compared to non-affected (Perthes) side; P2: p-value for control compared to affected (Perthes) side; P3: p-value for normal compared to unaffected (Perthes) side; E0: effect size for control group compared to Perthes group; E1: effect size for affected side compared to non-affected (Perthes) side; E2: effect size for control compared to affected (Perthes) side; E3: effect size for the control compared to unaffected (Perthes) side.



Key: —— Non-affected (Perthes) leg; —— Affected (Perthes) leg; ▨ Reference (control) data.

Figure 20: Walking data (Frontal plane)

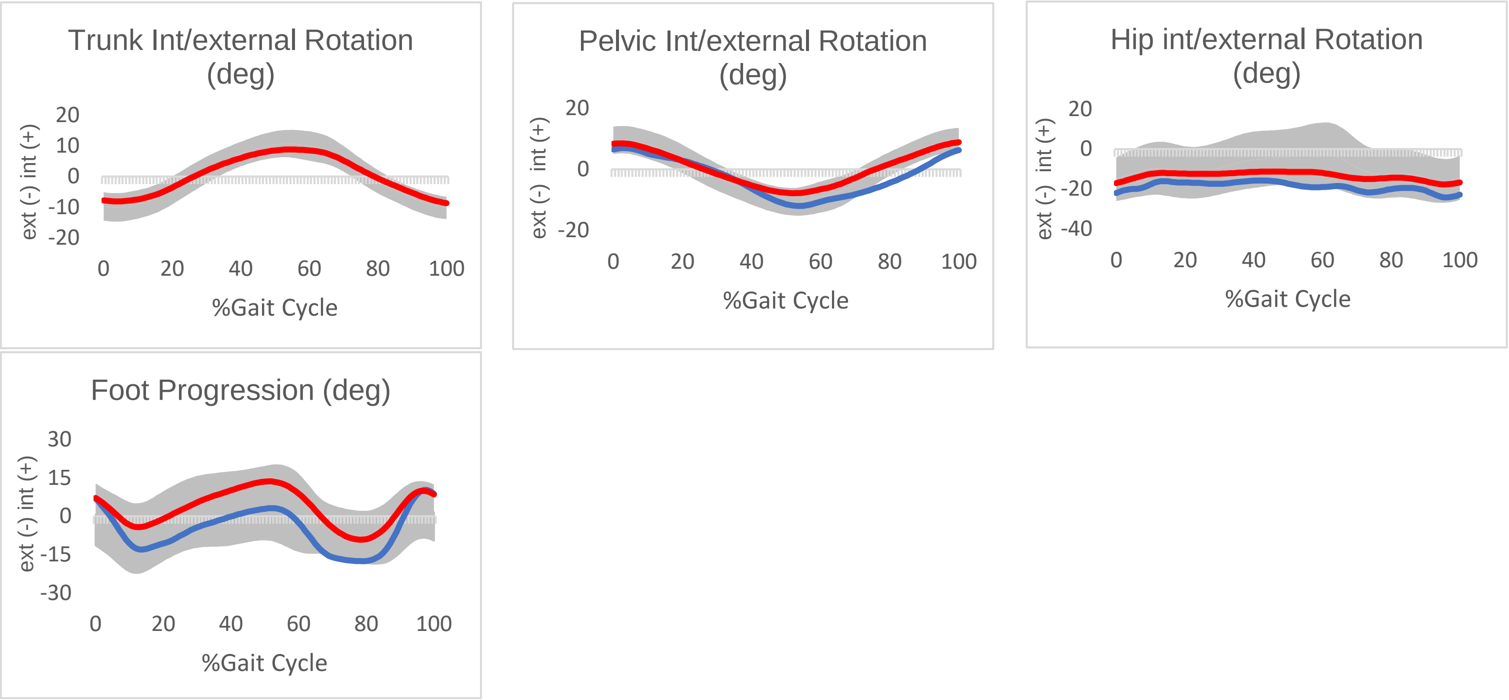
5.4.4.4 Walking activity parameters: Transverse plane

Table 29 and figure 21 show comparisons for compensation in walking movement between affected and non-affected Perthes legs and controls in the transverse plane. The Perthes group demonstrated a statistically significant decrease in trunk rotation ROM ($p<0.05$) due to a decrease in minimum trunk internal rotation by approximately 2°. The affected Perthes leg showed a statistically significant decrease in the pelvis and hip rotation ROM ($p<0.05$) by approximately 4° and 7°, respectively, due to a decrease in minimum pelvis internal rotation by approximately 3° and decrease in maximum hip internal rotation by approximately 9°. There is no statistically significant difference between affected Perthes leg and control groups in foot progression ($p<0.05$). The non-affected Perthes leg demonstrated a statistically significant difference in minimum pelvis internal rotation than the control group ($p<0.05$) by approximately 1°. The hip and foot progression ROM showed a statistically significant difference between non-affected Perthes leg and the control group ($P<0.05$), due to an increase in maximum and minimum hip and foot internal rotation by approximately 13° and 9°, respectively. Comparing affected Perthes leg to non-affected Perthes leg, the hip rotation ROM showed a statistically significant difference ($p<0.05$) due to increase minimum hip rotation in non-affected Perthes leg by approximately 6°.

Table 29: Walking activity parameters (transverse plane)

Parameters		Control Mean (± SD)	Perthes Mean (± SD)		P0					E0
			Affected	Non-affected						
Trunk	Maximum int Rot (°)	10.743 (±4.795)	8.822 (±4.867)		0.357					
	Minimum int Rot (°)	-10.256 (±3.557)	-8.708 (±3.439)		0.082					
	ROM (°)	20.999 (±1.239)	17.531 (±1.428)		**0.011**					**0.285**
					P1	**E1**	**P2**	**E2**	**P3**	**E3**
Pelvis	Maximum int Rot (°)	9.902 (±5.139)	8.835 (±5.191)	6.935 (±7.377)	0.489		0.393		**0**.324	
	Minimum int Rot (°)	-10.613 (±3.592)	-7.824 (±3.393)	-11.975 (±4.624)	0.077		0.051		0.030	**0.214**
	ROM (°)	20.515 (±1.548)	16.659 (± 1.798)	18.911 (±2.754)	0.113		**0.003**	**0.366**	0.556	
Hip	Maximum int Rot (°)	-2.571 (±16.137)	-11.267 (±13.200)	-15.734 (±26.557)	0.796		0.186		0.357	
	Minimum int Rot (°)	-15.947 (±10.930)	-17.684 (±9.501)	-24.247 (±19.083)	**0.040**	**0.196**	0.896		**0.021**	0.043
	ROM (°)	13.376 (±5.207)	6.417 (±3.699)	8.513 (±7.474)	**0.001**	**0.472**	**0.001**	**0.438**	0.049	**0.241**
Foot	Maximum int Rot (°)	5.378 (±15.604)	13.598 (±13.816)	10.217 (±22.167)	0.730		0.209		0.647	
	Minimum int Rot (°)	-8.587 (±9.341)	-9.202 (±9.463)	-17.598 (±16.542)	0.136		0.896		0.262	
	ROM (°)	13.966 (±6.263)	22.799 (±4.353)	27.815 (±5.624)	0.161		0.126		**0.017**	0.062

Key: **Bold** indicates significant value; SD: standard deviation; °: degree; P0: p-value for control group compared to Perthes group. P1: p-value for affected side compared to non-affected (Perthes) side; P2: p-value for control compared to affected (Perthes) side; P3: p-value for normal compared to unaffected (Perthes) side; E0: effect size for control group compared to Perthes group; E1: effect size for affected side compared to non-affected (Perthes) side; E2: effect size for control compared to affected (Perthes) side; E3: effect size for the control compared to unaffected (Perthes) side.



Key: ____ Non-affected (Perthes) leg; ____ Affected (Perthes) leg; ▨ Reference (control) data.

Figure 21: Walking data (Transverse plane)

5.4.5 Single-leg balance activity parameters

Table 30 and figure 22 demonstrate differences in single-leg balance between control and Perthes groups (including both legs). The temporospatial parameters indicate that the COP area was not a statistically significant difference between both Perthes legs and control groups (p>0.05); however, there is a statistically significant lower of COP velocity in the mediolateral direction by approximately 1.2 second.

The kinematic data shows only a statistically significant difference in minimum trunk obliquity in non-affected Perthes leg and hip flexion in affected Perthes leg compared to the control group (p<0.05). Both groups (including Perthes legs) displayed anterior tilt at the trunk level, with no statistically significant difference (p>0.05). This anterior trunk tilt was higher on both Perthes legs compared to control by approximately 5°. The trunk obliquity demonstrated no statistically significant difference in maximum trunk obliquity between the affected Perthes leg and control group. Standing on the non-affected Perthes leg revealed a statistically significant difference (p<0.05) between non-affected Perthes leg in less minimum trunk obliquity than the control group by approximately 2.5°. The trunk rotation showed no statistically significant difference between Perthes legs and the control group (p<0.05).

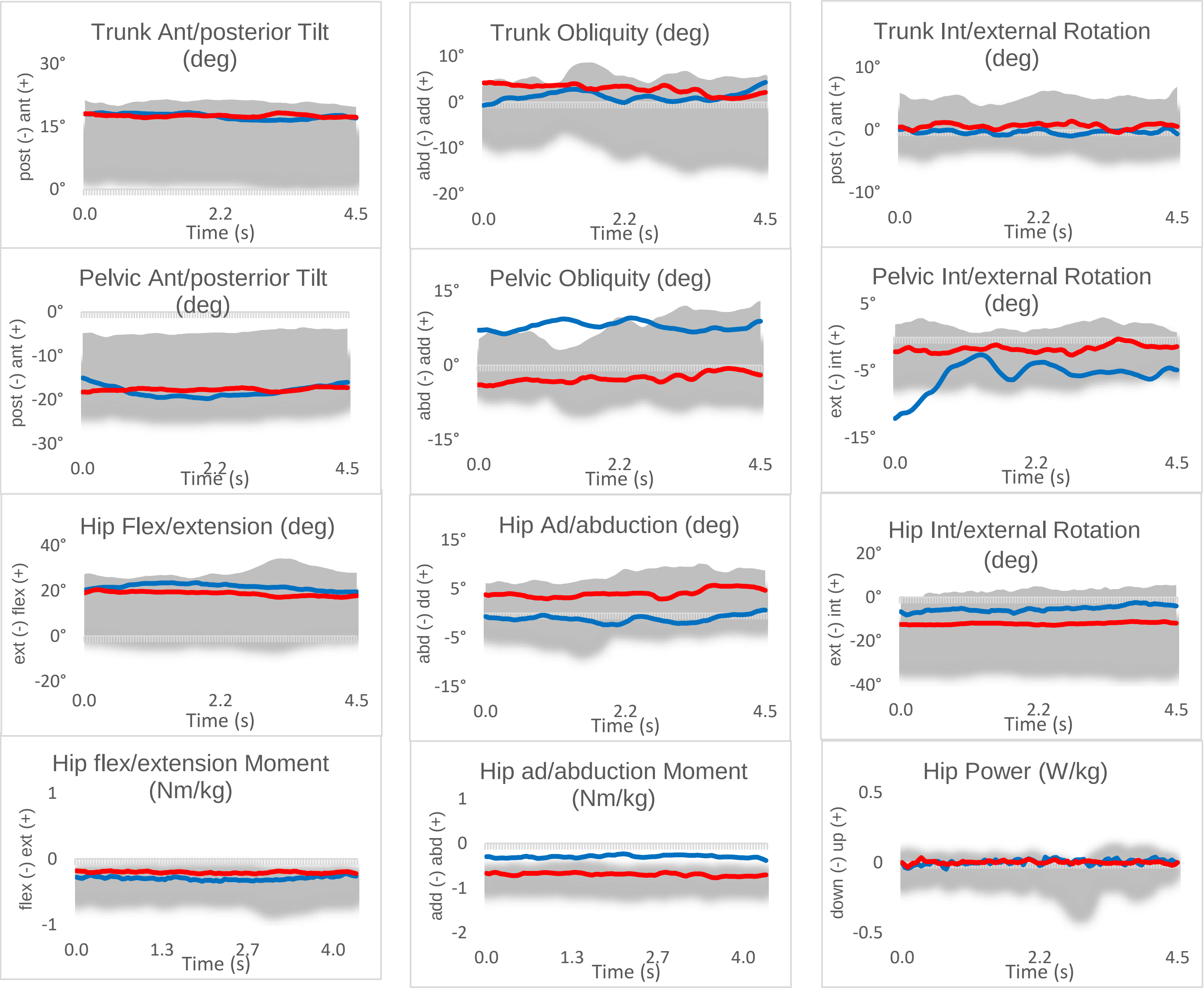
There is no statistically significant difference between Perthes legs and the control group at the pelvis level in pelvic tilt, obliquity, and rotation (p<0.05). At the hip level, the affected Perthes leg demonstrated a significant increase in hip flexion than the control group by approximately 4°. The non-affected Perthes leg showed no statistically significant difference compared to the control group (p>0.05). There is no statistically significant difference between Perthes legs and the control group in hip adduction and rotation (p>0.05).

The kinetic data shows that the hip extensor moment's peak was statistically significantly higher in both Perthes legs compared to the control group by approximately 0.1 (Nm/kg). The peak of hip abductor moment was statistically significantly lower in non-affected Perthes leg compared to the control group by approximately 0.3 (Nm/kg). There is no statistically significant difference between affected and non-affected Perthes leg in the peak of hip abductor moment (p>0.05). The hip power peak was significantly higher in non-affected Perthes leg than in control by approximately 0.01 (W/kg). The peak of vertical GRF was not a statistically significant difference between both Perthes legs and the control group.

Table 30: Single-leg balance activity parameters

Parameters			Control Mean (± SD)	Perthes Mean (± SD)		P1	E1	P2	E2	P3	E3
				Affected	Non-affected						
Temporospatial parameters											
COP area (m)		Ant/posterior	0.009 (± 0.006)	0.006 (± 0.007)	0.007 (± 0.005)	0.743		0.395		0.230	
		Medio/lateral	0.014 (± 0.014)	0.015 (± 0.008)	0.012 (± 0.013)	0.423		0.129		0.503	
COP velocity (s)		Ant/posterior	0.086 (± 0.077)	0.076 (± 0.074)	0.134 (± 0.156)	0.743		0.904		0.552	
		Medio/lateral	0.139 (± 0.147)	0.08 (± 0.087)	0.132 (± 0.151)	0.200		**0.02**	**0.281**	0.295	
COP area (m^2/s)			0.010 (± 0.008)	0.014 (± 0.009)	0.004 (± 0.015)	0.888		0.075		0.261	
Kinematic parameters											
Trunk	Tilt (°)	Maximum	13.331 (± 8.631)	18.316 (± 11.215)	18.40(± 10.739)	0.535		0.447		0.945	
		Minimum	11.825 (± 7.148)	17.142 (± 10.052)	16.473 (± 9.196)	0.456		0.142		0.49	
	Obliquity (°)	Maximum	2.004 (± 9.018)	4.301 (± 9.733)	4.327 (± 6.776)	0.165		0.49		0.332	
		Minimum	-3.209 (± 3.499)	0.767 (± 3.508)	-0.684 (± 3.676)	0.259		0.185		**0.017**	**0.265**
	Rotation (°)	Maximum	2.469 (± 4.515)	1.427 (± 4.061)	0.303 (± 4.757)	0.456		0.185		0.332	
		Minimum	1.048 (± 2.330)	-0.401 (± 1.761)	-0.966 (± 2.066)	0.805		0.731		0.891	
Pelvis	Tilt (°)	Maximum	-11.379 (± 8.596)	-17.007 (± 11.073)	-15.01(± 11.179)	0.097		0.078		0.63	
		Minimum	-13.442 (± 7.293)	-18.287 (± 10.200)	-19.75 (± 7.834)	0.535		0.237		0.49	
	Obliquity (°)	Maximum	3.556 (± 9.469)	-0.637 (± 10.155)	9.483 (± 9.565)	0.71		0.267		0.837	
		Minimum	-1.628 (± 3.385)	-4.162 (± 3.668)	5.40 (± 6.328)	0.535		0.091		0.368	
	Rotation (°)	Maximum	-0.573 (± 3.984)	-0.209 (± 3.862)	-2.58 (± 16.544)	0.902		0.298		0.945	
		Minimum	-2.411 (± 2.135)	-2.618 (± 1.536)	-12.1 (± 9.939)	0.259		0.581		0.142	
Hip	Flexion (°)	Maximum	17.794 (± 17.128)	20.498 (± 10.146)	23.559 (± 13.11)	0.902		0.945		0.837	
		Minimum	13.722 (± 11.303)	17.085 (± 7.358)	19.408 (± 10.03)	0.805		**0.011**	**0.298**	0.078	
	Adduction (°)	Maximum	4.287 (± 6.301)	5.717 (± 9.368)	0.645 (± 12.807)	0.902		0.267		0.49	
		Minimum	0.438 (± 4.319)	2.910 (± 6.640)	-2.387 (± 5.87)	0.62		0.945		0.731	
	Rotation (°)	Maximum	-11.841 (± 17.84)	-11.019 (± 16.553)	-2.38(± 32.513)	0.71		0.945		0.535	
		Minimum	-14.658 (± 14.44)	-12.738 (± 15.190)	-8.04(± 28.853)	0.535		0.49		0.837	
Kinetic parameters											
Peak of hip extensor moment (Nm/kg)			-0.178 (± 0.209)	-0.215 (± 0.149)	-0.287 (± 0.191)	0.200		**0.001**	**0.667**	**0.001**	**0.675**
Peak of hip abductor moment (Nm/kg)			-0.505 (± 0.323)	-0.693 (± 0.330)	-0.214 (± 0.256)	**0.001**	**0.667**	0.122		**0.028**	**0.243**
Peak of hip power (W/kg)			0.049 (± 0.137)	0.038 (± 0.068)	0.059 (± 0.138)	0.114	**0.157**	0.408		**0.043**	**0.188**
Peak of vertical GRF (%BW)			0.917 (± 0.226)	1.031 (± 0.145)	0.982 (± 0.177)	0.321		0.203		0.356	

Key: **Bold** indicates significant value; SD: standard deviation; °: degree; m: meter; s: second; COP: centre of pressure; N: newton; W: watt; kg: kilogram; P1: p-value for affected (Perthes) side compared to non-affected (Perthes) side; P2: p-value for normal compared to affected (Perthes) side; P3: p-value for control compared to non-affected (Perthes) side. E1: effect size for affected side compared to non-affected (Perthes) side; E2: effect size for control compared to affected (Perthes) side; E3: effect size for the control compared to unaffected (Perthes) side.



Key: ____ Non-affected (Perthes) leg; ____ Affected (Perthes) leg; ▨ Reference (control) data.

Figure 22: Single-leg balance data

5.4.6 Squat activity parameters

Table 31 and figure 23 demonstrate compensation mechanisms in both legs in the Perthes group during the squat activity, mainly at the trunk, pelvis ROM and kinetic parameters. The ROM in the trunk and pelvis (obliquity and rotation) were statistically significantly higher by approximately 2° compared to the control group. The Perthes group showed no statistically significant difference between both legs and the control group in hip flex/extension, ad/abduction, and rotation ROM (p>0.05). At the knee level, the Perthes group showed no statistically significant difference in Knee ROM between both Perthes legs and the control group. The minimum knee flexion showed a statistically significant difference (p<0.05) between affected Perthes leg and non-affected Perthes leg by approximately 0.6°, however, the effect size indicates that this difference in minimum knee flexion between both Perthes legs is small (0.01). At the ankle level, the Perthes group showed a statistically significant difference in ankle ROM compared to the control group, which decreased in affected Perthes by approximately 1.5 and increased non-affected Perthes leg by approximately 1.2. However, this statistically significant difference between the Perthes and control groups in ankle ROM showed small to medium effect sizes (<0.09).

The kinetic data showed no statistically significant difference between both Perthes leg and control group in the peak of hip extensor moment (p>0.05). The peak of hip abductor moment was statistically significantly lower (p<0.05) with a large effect size (0.233) in non-affected Perthes leg compared to control by approximately 0.14 (Nm/kg). The knee abductor moment peak was statistically significantly lower between Perthes legs and the control group (p<0.05). This statistically significant difference in the peak of knee abductor moment in the affected Perthes leg showed a small effect size (0.001), while the non-affected Perthes leg showed a large effect size (0.525). The peak of hip power and the peak of GRF revealed no statistically significant difference between both Perthes legs and the control group (p>0.05).

Table 31: Squat activity parameters

Parameters			Control Mean (± SD)	Perthes Mean (± SD)		P0					E0
				Affected side	Non-affected side						
Kinematic parameters											
Trunk	Flexion (°)	Maximum	13.472 (± 15.345)	19.649 (± 12.294)		0.416					
		Minimum	5.492 (± 9.022)	3.379 (± 2.958)		0.701					
		ROM	7.981 (± 6.323)	16.269 (± 9.521)		0.244					
	Obliquity (°)	Maximum	1.336 (± 5.762)	2.437 (± 7.608)		0.152					
		Minimum	-1.004 (± 2.910)	-2.628 (± 1.436)		0.282					
		ROM	2.34 (± 2.851)	5.065 (± 6.169)		**0.002**					**0.441**
	Rotation (°)	Maximum	2.039 (±5.069)	2.194 (± 6.0737)		0.244					
		Minimum	-0.118 (±3.099)	-0.941 (± 1.399)		0210					
		ROM	2.157 (±1.970)	3.135 (± 4.674)		**0.007**					**0.364**
Pelvis	Tilt (°)	Maximum	-5.414 (± 15.442)	-3.287 (± 12.83)		0.639					
		Minimum	-13.321 (± 9.161)	-19.529 (± 2.924)		0.416					
		ROM	7.907 (± 6.281)	16.241 (± 9.259)		0.368					
	Obliquity (°)	Maximum	0.633 (± 5.532)	2.922 (± 7.617)		0.125					
		Minimum	-1.96 (± 2.427)	-2.923 (± 1.351)		0.179					
		ROM	2.593 (± 3.105)	5.845 (± 6.266)		**0.002**					**0.441**
	Rotation (°)	Maximum	-0.423 (± 4.808)	0.227 (± 4.357)		0.368					
		Minimum	-2.199 (± 3.293)	-2.259 (± 1.104)		0.282					
		ROM	1.776 (± 1.514)	2.486 (± 3.253)		**0.036**					**0.233**
						P1	E1	P2	E2	P3	E3
Hip	Flexion (°)	Maximum	50.289 (± 43.392)	75.692 (± 42.938)	73.226 (± 45.355)	0.937		0.179		0.179	
		Minimum	9.752 (± 14.587)	15.699 (± 6.329)	14.407 (± 9.088)	0.818		0.282		0.579	
		ROM	40.538 (± 7.189)	59.993 (± 36.609)	58.819 (± 36.267)	0.937		0.323		0.210	
	Adduction (°)	Maximum	-0.399 (± 12.703)	1.132 (± 14.297)	-4.362 (±11.243)	0.394		0.416		0.579	
		Minimum	-10.553 (± 3.498)	-9.836 (± 3.592)	-13.439 (±2.656)	0.485		0.323		0.898	
		ROM	10.553 (± 9.205)	10.968 (± 10.705)	18.217 (± 8.586)	0.937		0.416		0.521	
	Rotation (°)	Maximum	-11.456 (± 21.389)	-4.895 (± 24.293)	4.778 (± 29.659)	0.132		0.898		0.179	
		Minimum	-18.647 (± 15.861)	-19.883 (± 10.862)	-13.439 (±13.765)	1.00		0.831		0.966	
		ROM	7.189 (± 5.529)	14.988 (± 13.432)	18.217 (±15.894)	0.240		0.701		0.127	
Knee	Flexion (°)	Maximum	61.543 (±60.191)	76.549 (± 46.117)	76.401 (±40.992)	0.699		0.765		0.898	
		Minimum	-3.617 (±10.161)	1.108 (± 5.491)	-0.579 (±5.582)	0.937		**0.007**	0.010	0.072	
		ROM	65.161 (±50.031)	75.441 (± 40.626)	76.981 (±35.409)	0.485		0.210		0.467	
Ankle	Flexion (°)	Maximum	23.557 (± 23.637)	21.567 (±18.669)	23.348 (± 18.067)	0.589		**0.046**	0.006	0.210	
		Minimum	-3.811(± 6.338)	-4.115 (±3.907)	-4.149 (±4.050)	0.818		**0.036**	**0.364**	0.179	
		ROM	27.368 (± 17.299)	25.682 (±14.763)	27.498 (±14.017)	0.485		**0.002**	0.091	**0.017**	0.033
Kinetic parameters											
Peak of hip extensor moment (Nm/kg)			0.468 (± 0.603)	0.723 (± 0.481)	0.822 (± 0.629)	1.00		0.701		0.368	
Peak of hip abductor moment (Nm/kg)			0.291 (± 0.262)	0.258 (± 0.300)	0.149 (± 0.267)	0.699		0.210		**0.036**	**0.233**
Peak of knee abductor moment (Nm/kg)			0.246 (± 0.234)	0.229 (± 0.276)	0.095 (± 0.211)	**0.015**	0.001	0.282		**0.001**	**0.525**
Peak of hip power (W/kg)			0.659 (± 1.268)	0.757 (± 1.225)	1.048 (±1.835)	0.818		0.521		0.639	
Peak of vertical GRF on douple leg squat (%BW)			0.668 (± 0.206)	0.616 (± 0.233)	0.579 (± 0.331)	0.094		0.462		0.121	

Key: **Bold** indicates significant value; SD: standard deviation; °: degree; m: metre; N: newton; W: watt; kg: kilogram; P0: p-value compared Perthes to control; P1: p-value for affected (Perthes) side compared to non-affected (Perthes) side; P2: p-value for normal compared to affected (Perthes) side; P3: p-value for control compared to non-affected (Perthes) side.E0: effect size for Perthes group compared to control; E1: effect size for affected side compared to non-affected (Perthes) side; E2: effect size for control compared to affected (Perthes) side; E3: effect size for the control compared to unaffected (Perthes) side.

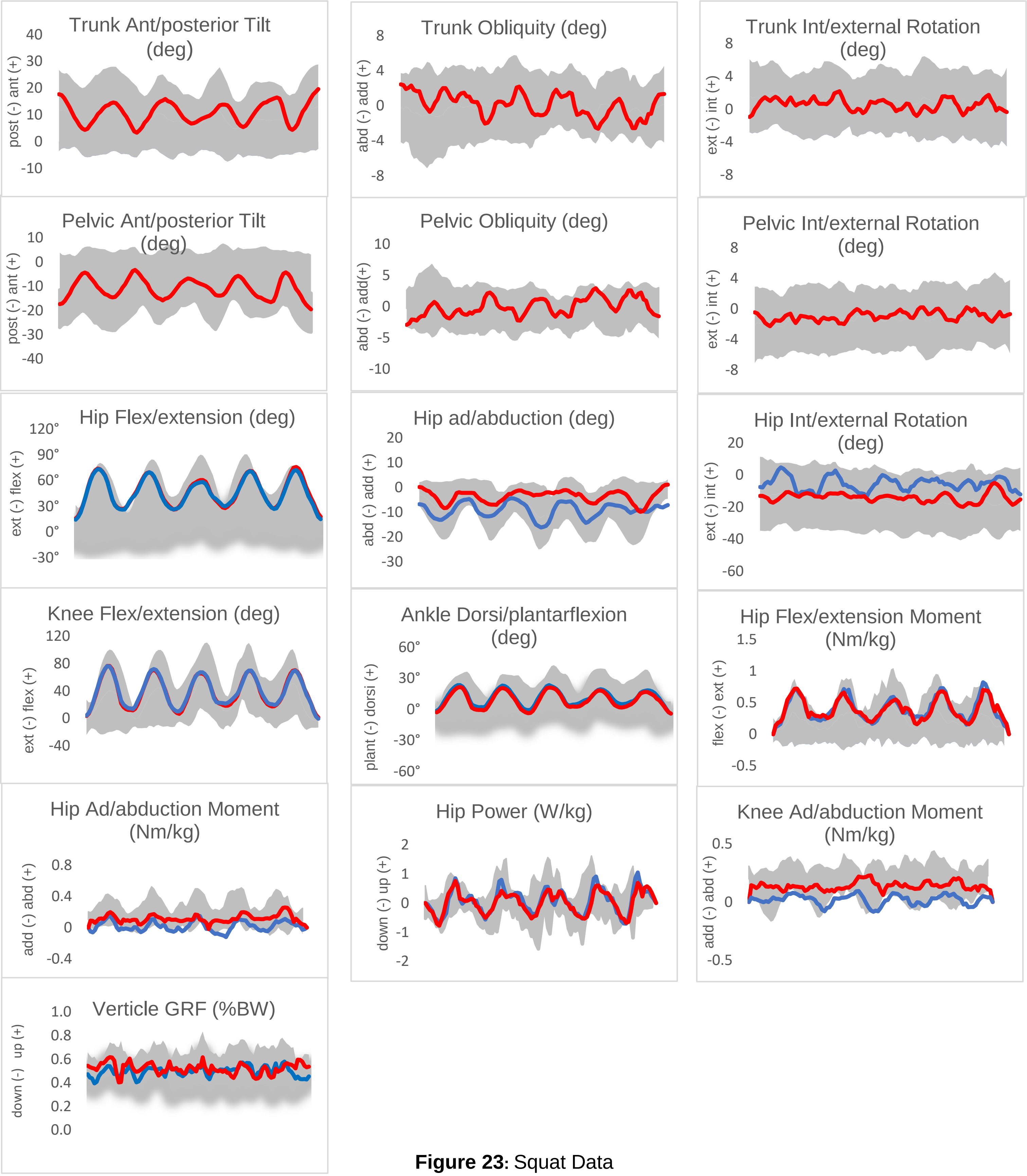


Figure 23: Squat Data

Key: ____ Non-affected (Perthes) leg; ____ Affected (Perthes) leg; ▨ Reference (control) data.

5.4.7 Summary of functional activities results

In order to investigate movement compensation, fifteen control children and nine children with Perthes performed three different functional activities. The Perthes stages of the children were mild and moderate. Before comparing functional activity performance, passive ROM and muscle strength were measured. The Perthes group demonstrated no statistically significant difference in passive joint ROM and muscle strength than the control group ($p>0.05$). The walking data indicate differences in temporospatial, kinematic and kinetic parameters in three planes (sagittal, frontal, and transverse). Temporospatial parameters revealed only statistically significant differences in stride width, narrow in the Perthes group ($p<0.05$). In the sagittal plane, the Perthes group displayed statically significant lower minimum hip flexion in both Perthes legs compared to the control group by approximately 7°. The kinetic data show no statistically significant difference between control and Perthes groups in all parameters ($p>0.05$). However, the affected Perthes leg generated less ankle power by approximately 0.4 (W/kg) than the non-affected leg with a large effect size (0.149).

In the frontal plane, the affected Perthes leg (at single limb support) showed a statistically significant difference ($p<0.05$) compared to control as demonstrated slight trunk lean towards the stance limb and less hip adduction by approximately 1.3° and 1.7 °, respectively. The non-affected Perthes leg demonstrated a statistically significant difference in the pelvis and knee ROM ($p<0.05$) due to reduced maximum and minimum pelvis and knee adduction by approximately 3° and 7°, respectively. Comparing affected Perthes leg to non-affected Perthes leg, there is a statistically significant difference in pelvis and knee adduction ROM ($p<0.05$) due to less minimum pelvis adduction and maximum knee adduction by approximately 6° and 9°, respectively. In the kinetic data, the peak of hip abductor moment was significantly higher in the Perthes group than the control group by approximately 0.06 Nm/kg, respectively.

The Perthes group demonstrated a statistically significant decrease in trunk rotation ROM ($p<0.05$) in the transverse plane due to a decrease in minimum trunk internal rotation. The affected Perthes leg showed a statistically significant decrease in the pelvis and hip rotation ROM ($p<0.05$) by approximately 4° and 7°, respectively, due to a decrease in minimum pelvis internal rotation by approximately 3° and decrease in maximum hip internal rotation by approximately 9°. The non-affected Perthes leg demonstrated a statistically significant difference in minimum pelvis internal rotation than control ($p<0.05$) by approximately 1°. The hip and foot progression ROM showed a statistically significant difference between non-affected Perthes leg and the control group ($P<0.05$), due to increased maximum and minimum hip and foot internal rotation by approximately 13° and 9°, respectively. Comparing affected Perthes leg to non-affected Perthes leg, the hip rotation ROM showed a statistically significant difference (p<0.05) due to increase minimum hip rotation in non-affected Perthes leg by approximately 6°.

In single-leg balance activity, the temporospatial parameters indicate that the COP area was not statistically significant between the Perthes legs and control groups (p>0.05); however, COP velocity in the mediolateral direction was statistically significantly lower in standing with affected Perthes by the approximately 1.2 second. The kinematic data showed only a statistically significant difference in minimum trunk obliquity in non-affected Perthes leg and hip flexion in affected Perthes leg compared to the control group (p<0.05). The kinetic data showed that the hip extensor moment's peak was statistically significantly higher in both Perthes legs compared to the control group by approximately 0.1 (Nm/kg). The peak of hip abductor moment was statistically significantly lower in non-affected Perthes leg compared to the control group by approximately 0.3 (Nm/kg). The hip power peak was significantly higher in non-affected Perthes leg than in control by approximately 0.01 (W/kg).

In the squat activity, the Perthes group demonstrated a compensation mechanism during the squat activity, mainly at the trunk, pelvis ROM and kinetic parameters. The Perthes group displayed statistically significantly higher in the total of trunk and pelvis ROM (obliquity and rotation) in compared to controls (p<0.05) by approximately 3° and 1°, respectively. The kinetic data showed that the hip and knee abductor moment's peak was statistically significantly lower in the non-affected Perthes leg compared to the control group by approximately 0.15 (Nm/kg).

In conclusion, the children with Perthes demonstrated compensation mechanisms in both affected and non-affected legs. The three functional activities demonstrated deviation in temporospatial, kinematic and kinetic data.

5.4.8 Questionnaire results

All children with Perthes who participated in the functional activities task and their parents are included in this section, divided into two subsections. The first compares the findings of the physical activity (PAQ-C) and KIDSCREEN-10 questionnaires between the Perthes and control groups. The second presents the Managing of physiotherapy treatment with children with Perthes and their families questionnaire.

5.4.8.1 Physical activity questionnaire (PAQ-C)

The PAQ-C measures mode, frequency, and duration of physical and sedentary activities across all domains over the previous seven days. The mean and standard deviations (SD) of total hours for each domain were calculated for weekday and weekend days, and the results are presented in Table 32.

Table 32: Physical activity questionnaire (PAQ-C)

Domain	Control Mean (± SD)		Perthes Mean (± SD)		P1	P2
	Hours/weekday	Hours/weekend day	Hours/weekday	Hours/weekend day		
Sports activities	3.787 (± 2.355)	1.657 (± 1.106)	2.167 (± 2.682)	0.839 (± 0.884)	0.446	0.238
Leisure time activities	1.843 (± 1.374)	1.333 (± 0.833)	3.565 (± 4.94)	0.963 (± 1.435)	0.815	0.238
Activities at school	1.269 (±0.692)		0.713 (± 1.01)		0.194	
Activities at home	17.407 (± 11.984)	13.722 (±8.288)	14.835 (± 13.826)	9.315 (± 5.243)	0.446	0.155

Key: **Bold** indicates significant value; P1: Significant difference between control and Perthes groups during weekdays; P2: Significant difference between control and Perthes groups during weekends.

The PAQ-C showed no statistically significant difference between Perthes and control groups in sports activities, leisure time activities, and activities at school and home (p>0.05). The Perthes group spent less time in sports activities per weekday and weekend day compared to controls, with a difference of approximately one hour. Time spent in leisure time activities was higher by approximately one hour in the Perthes group than controls during weekdays, but higher by approximately half an hour in the control group on weekend days. The Perthes group spent half an hour less than the control group on activities at school and approximately three hours less on activities at home on both weekdays and weekend days.

5.4.8.2 Health-related quality of life (KIDSCREEN-10) questionnaire

This questionnaire is used to measure health-related quality of life (HRQoL). It consists of ten questions, each of which is answered on a five-point response scale. Responses were all reported as means and standard deviations (SD). Rasch scores and T-values were calculated according to the KIDSCREEN-10 manual. As most of the responses were not normally distributed, the Kruskal-Wallis test was used to compare normal (control group) KIDSCREEN-10 T-values with Perthes group T-values and differences between the groups for individual KIDSCREEN-10 questions (Table 33 and Figure 24).

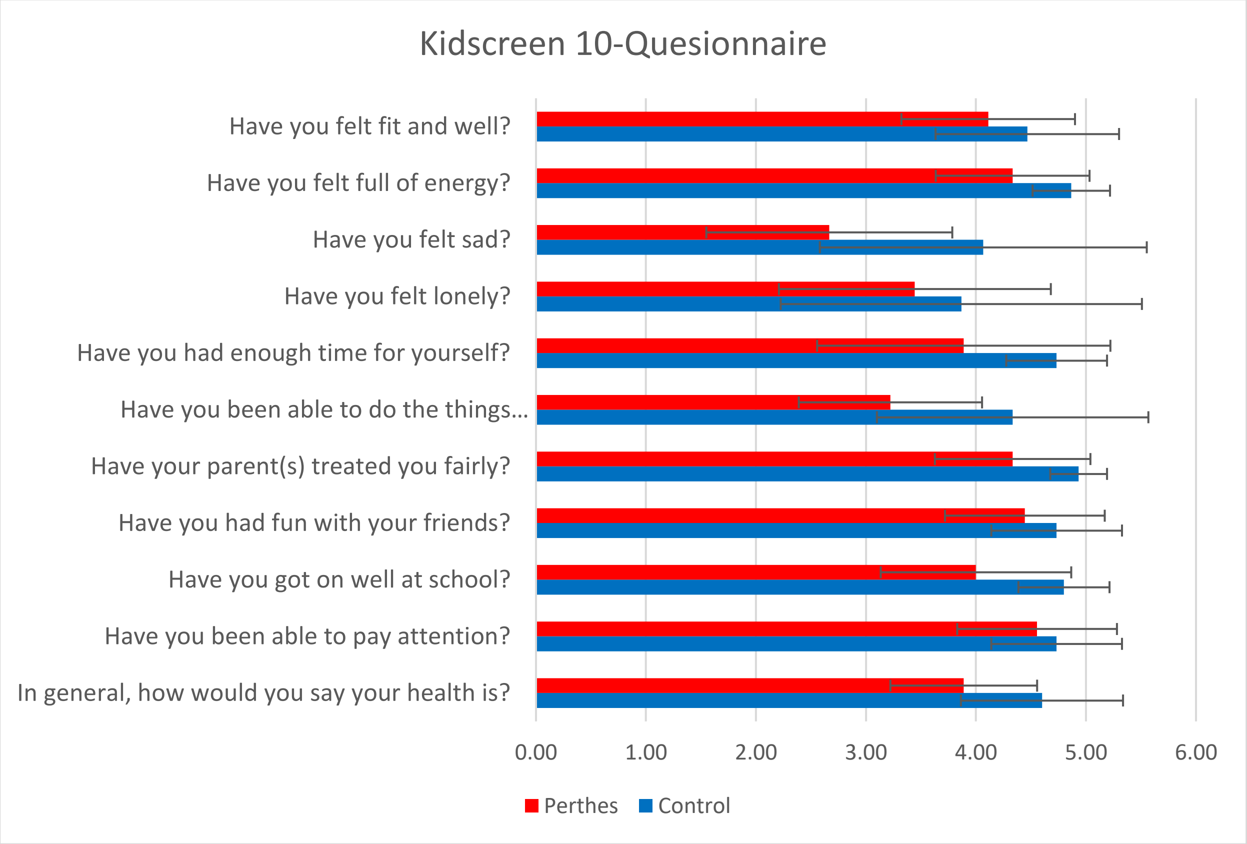


Figure 24: KIDSCREEN-10 questionnaire

Table 33: Health-related quality of life (KIDSCREEN-10) questionnaire

Questionnaire items	Control Mean (± SD)	Perthes Mean (± SD)	p
Have you felt fit and well?	4.467 (± 0.834)	4.111 (± 0.789)	0.29
Have you felt full of energy?	4.867 (± 0.352)	4.333 (± 0.699)	0.084
Have you felt sad?	4.067 (± 1.486)	2.667 (± 1.118)	**0.030**
Have you felt lonely?	3.867 (± 1.642)	3.444 (± 1.236)	0.29
Have you had enough time for yourself?	4.733 (± 0.458)	3.889 (± 1.333)	0.138
Have you been able to do the things that you want to do in your free time?	4.333 (± 1.234)	3.222 (± 0.833)	**0.007**
Have your parent(s) treated you fairly?	4.933 (± 0.258)	4.333 (± 0.707)	0.05
Have you had fun with your friends?	4.733 (± 0.594)	4.444 (± 0.726)	0.347
Have you got on well at school?	4.800 (± 0.414)	4.000 (± 0.866)	**0.03**
Have you been able to pay attention?	4.733 (± 0.594)	4.556 (± 0.726)	0.599
In general, how would you say your health is?	4.60 (± 0.737)	3.889 (± 0.667)	**0.021**
General HRQoL index (T-value)	52.469 (± 9.374)	47.833 (± 7.443)	**0.03**

Key: **Bold** indicates significant value; SD: standard deviation; P: p-value for control compared to Perthes group; HRQoL: health-related quality of life.

Table 33 and figure 24 compare the findings of the KIDSCREEN-10 questionnaire for control and children with Perthes. The T-value (general HRQoL index) was statistically significantly lower in the Perthes group than the control group, indicating the lower quality of life score for children with Perthes ($p<0.05$). The detailed analysis demonstrated that the Perthes group felt fit and powerful with no statistically significant difference compared to controls ($p>0.05$). However, psychological wellbeing was statistically significantly different between Perthes and control groups, as the Perthes group felt sad ($p<0.05$). Statistically significant difference was revealed within the Perthes group with regard to “time for yourself” and the organisation of free time ($p<0.05$). Furthermore, the Perthes group scored statistically significantly lower on paying attention at school than the control group ($p<0.05$). They also scored statistically significantly lower for their general health compared to controls ($p<0.05$).

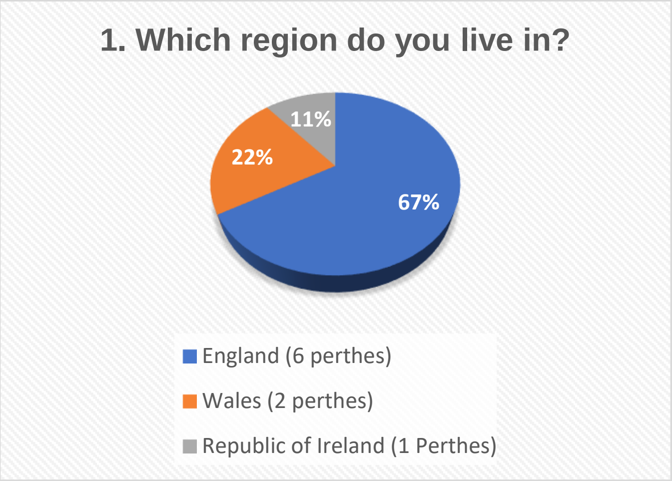
5.4.8.3 Managing physiotherapy treatment questionnaire

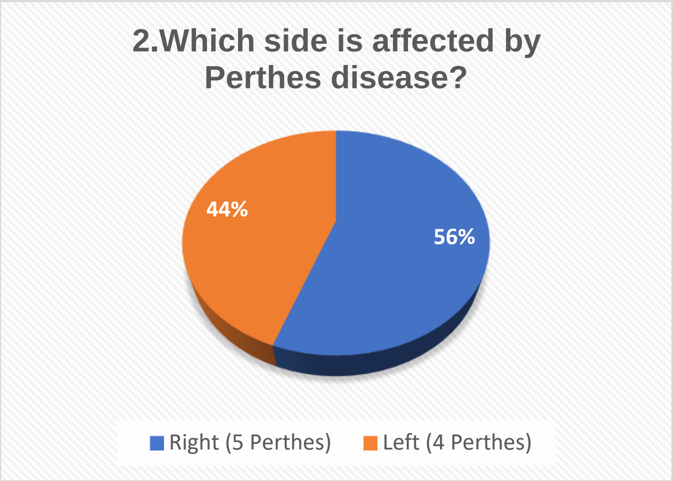
This questionnaire has two parts, one for children with Perthes and the other for their parents. The parent section includes 14 questions divided into five domains: demographic, diagnostic, physiotherapy practice, management of clinical provider advice, and concerns, and the child section comprises ten questions covering: physiotherapy practice, pain, and concerns. The results of this questionnaire are presented in pie charts reporting response frequency.

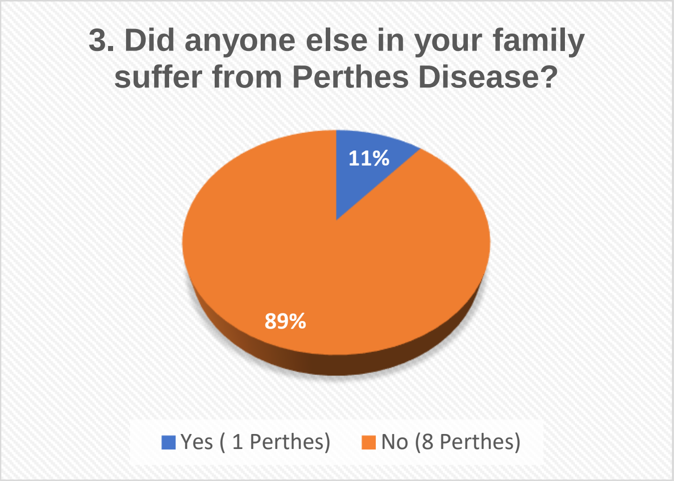
5.4.8.3a Parent questionnaire

A) Demographic domain

The demographic domain indicates that most participants live in England (six participants), two from Wales and one from the Republic of Ireland. There is near equality on the affected side: five children with Perthes had right-side involvement, and four had left-side involvement. Only one case demonstrated a positive family history of Perthes disease (questions 1–3).

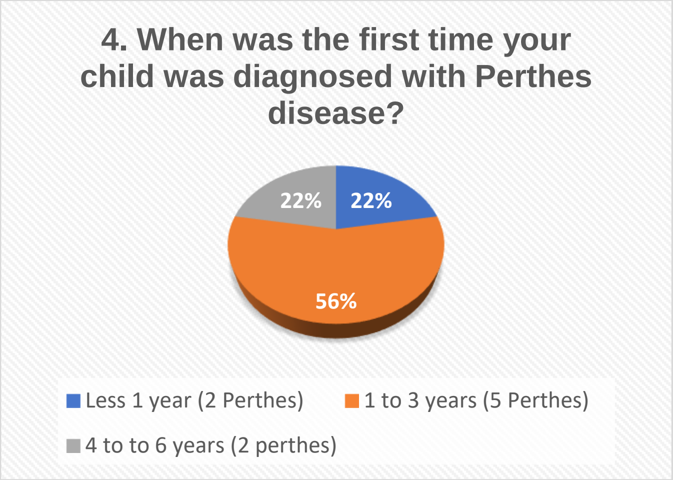


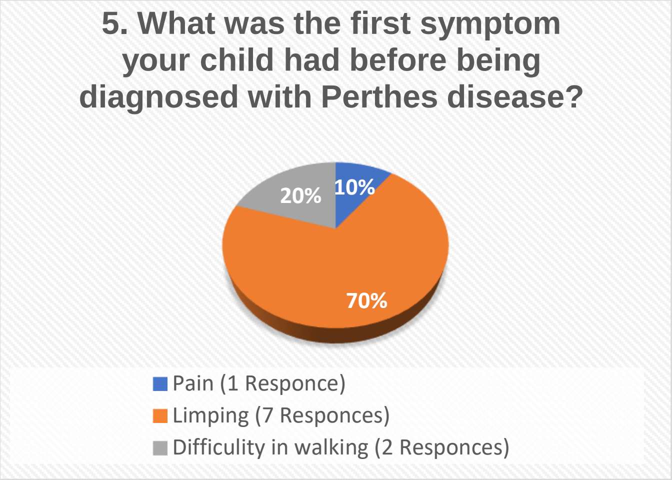


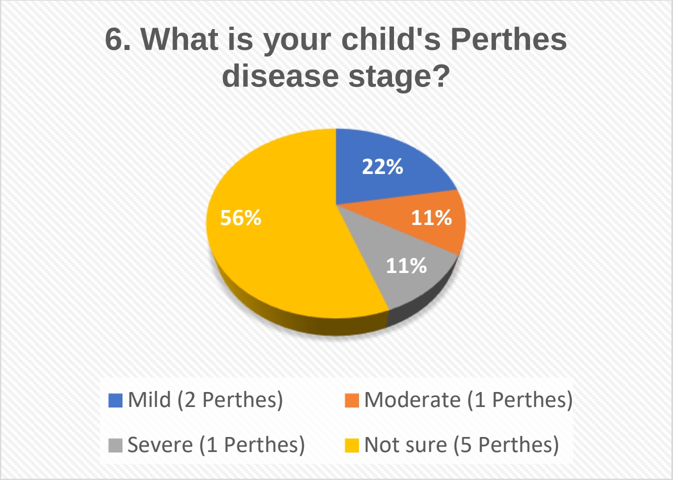


B) Diagnostic domain

The diagnostic domain shows that most children with Perthes in this study (five) received the diagnosis at between one and three years of age, while the rest received the diagnosis at less than one year or after three years of age. The vast majority of parents reported limping as the first symptom of Perthes disease (seven children), while two reported difficulties in walking and one reported pain level. The majority of parents (five) were not sure of the Perthes disease stage of their children, but two reported the stage as mild, one reported it as moderate, and one as severe (questions 4–6).

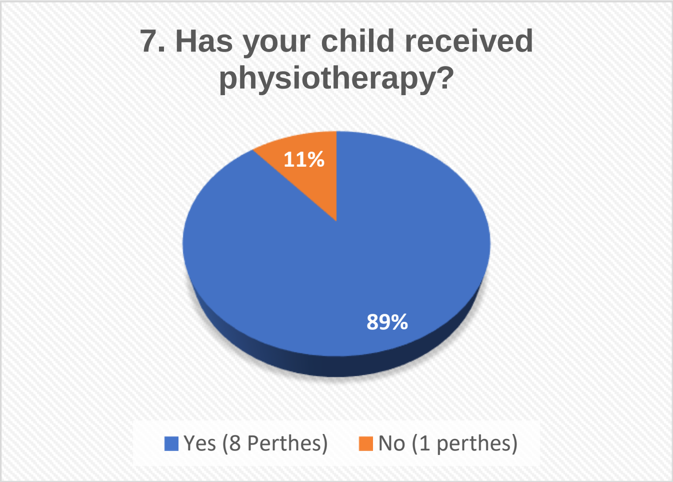


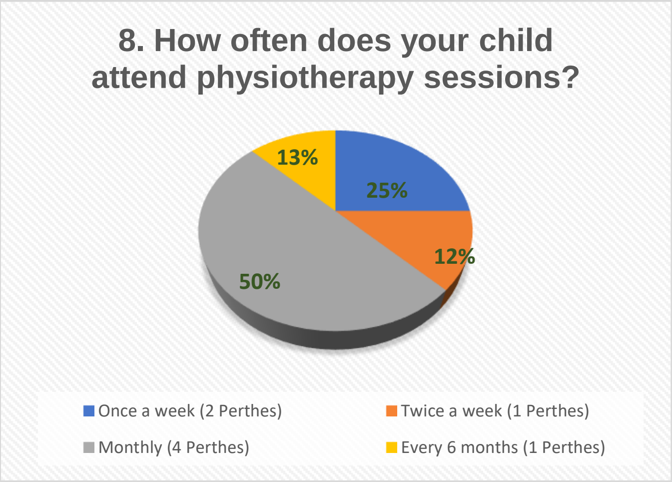


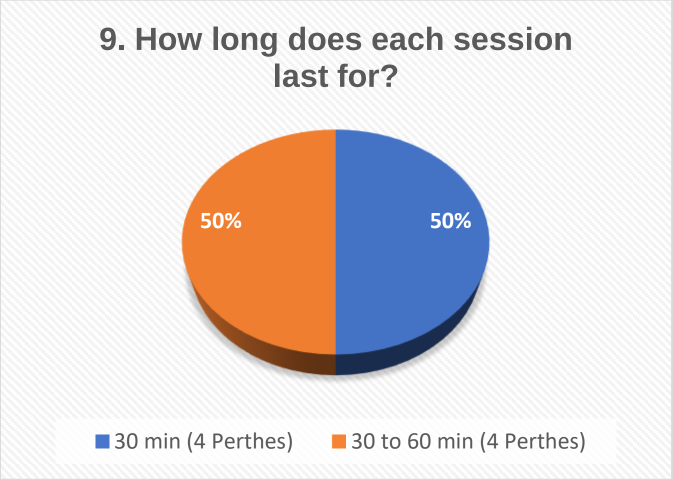


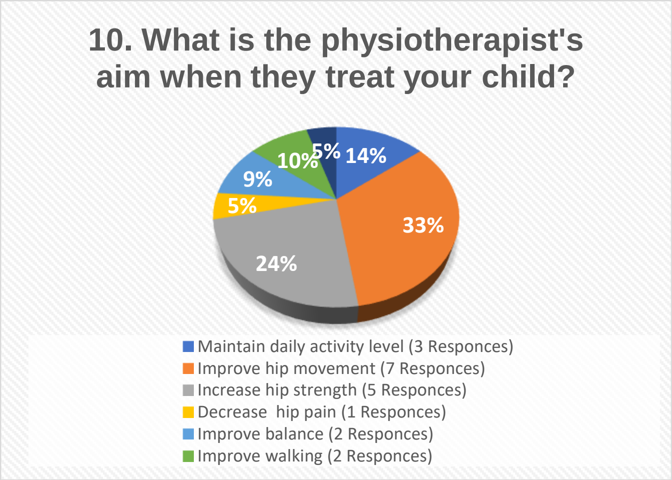
C) Physiotherapy practice domain

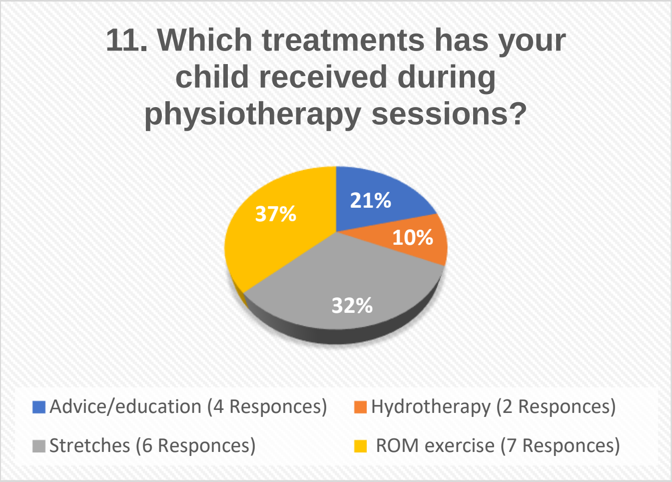
The physiotherapy practice domain illustrates clinical practice experience from the perspective of the parents of children with Perthes. All Perthes subjects except one were receiving physiotherapy treatment. Four children had a monthly physiotherapy session of 30 to 60 minutes (the time reported for sessions by all participants). Parents reported that physiotherapy's main objective is to improve hip movement (seven responses) and increase hip muscle strength (five responses). To "maintain daily activity" was chosen in three responses, and the aims of improving walking and balance were each selected twice. One respondent stated that decreasing hip pain and improving hip blood flow was a goal of physiotherapy treatment. The most common treatments received during physiotherapy sessions were ROM exercises (seven parent responses) and stretching exercises (six parent responses). Four parents reported receiving advice and education during sessions, while hydrotherapy was the least common treatment (two-parent responses) (questions 7–12).

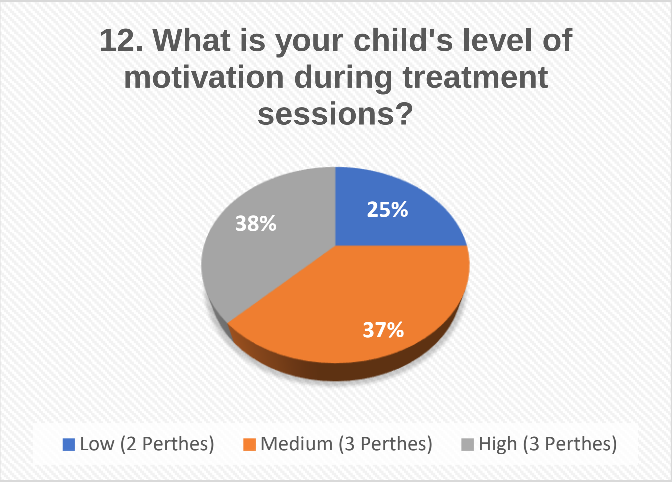






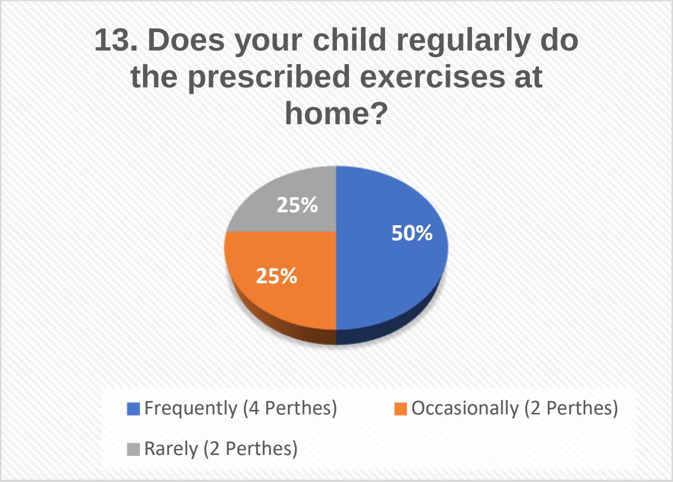






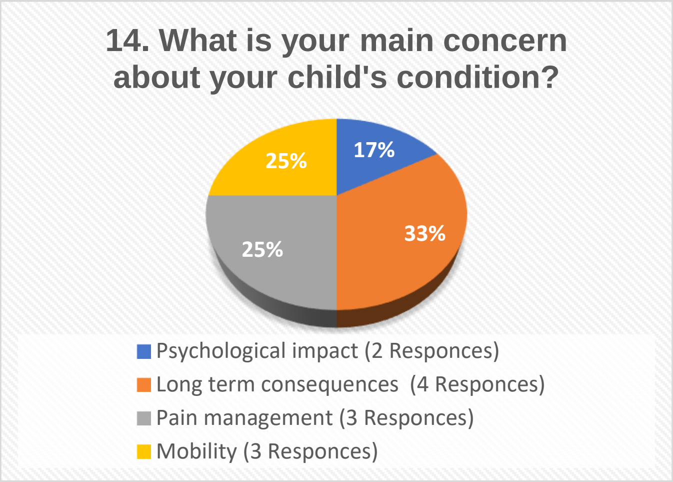
D) Clinical provider advice domain

The clinical provider advice domain shows that most children with Perthes frequently performed the prescribed physiotherapy exercises at home (four parents). However, parents reported that two children with Perthes did the exercises occasionally, and two did rarely (question 13).



E) Parents’ concerns domain

The last domain for parents is concerns. The concern reported most by parents (four responses) related to long-term consequences of Perthes disease, such as operation. Mobility and pain management were the second-most frequent concerns (three responses each). The psychological impact of Perthes disease (e.g., anxiety and feeling lonely) was mentioned by two parents (Question 14).

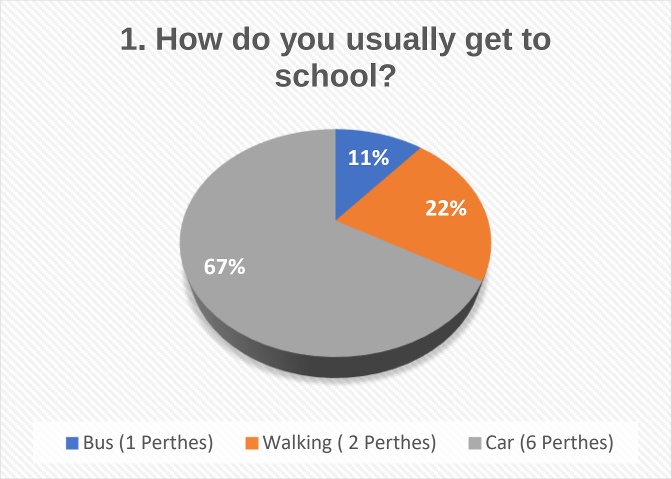


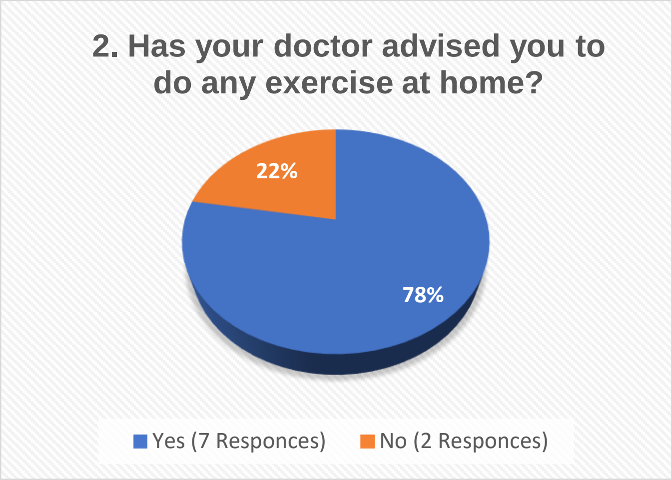
5.4.8.3b Child with Perthes questionnaire

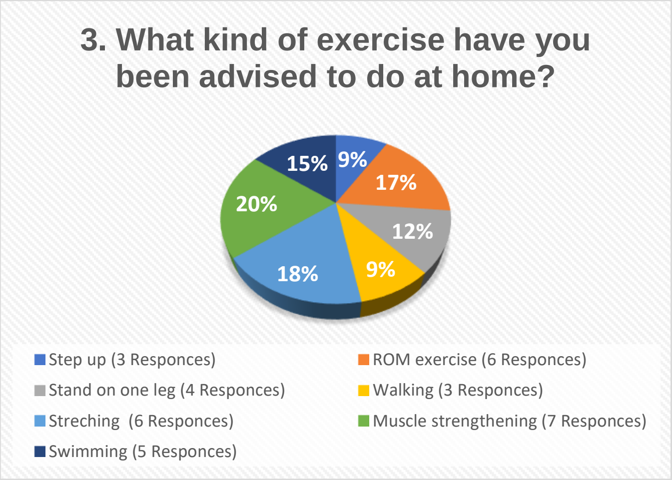
The questionnaire for children with Perthes includes ten questions divided into three domains: physiotherapy practice, pain management, and child’s concerns. The results of this questionnaire are presented as pie charts reporting the response frequency.

A) Physiotherapy practice domain

Most of the children with Perthes (seven) reported going to school by car, while two walked and one went by bus. Seven children with Perthes reported that the doctor had advised them to exercise at home, while two answered “no” to this question. The exercises children reported being advised to do at home were as follows: seven responses for muscle strengthening exercises, six responses for ROM exercises and stretching exercises, and three responses for each of standing on one leg, walking, and step-up exercises. Half of the children with Perthes reported “usually” doing the exercises at home, and the others responded “sometimes” (questions 1–4).

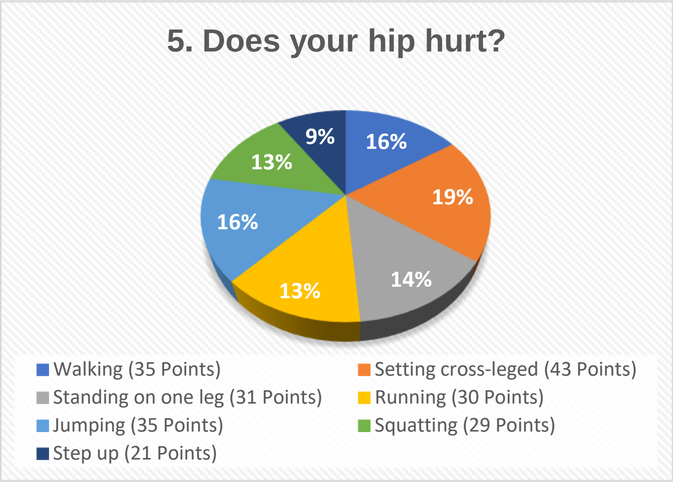


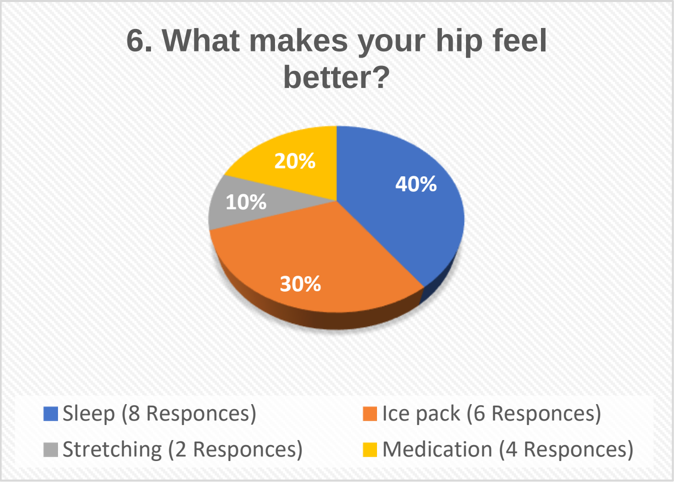


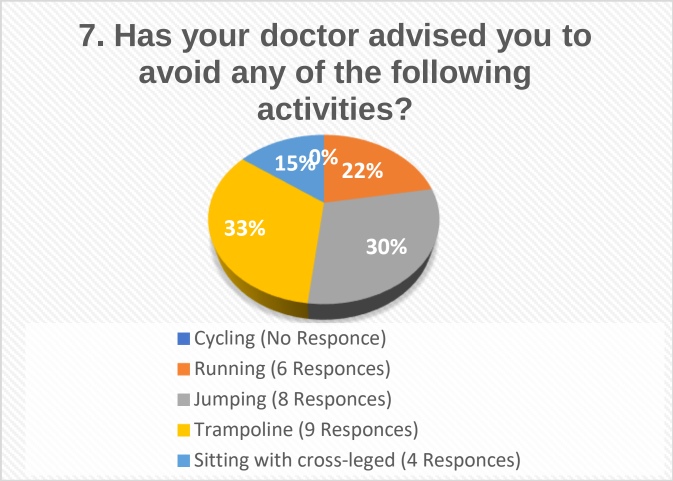


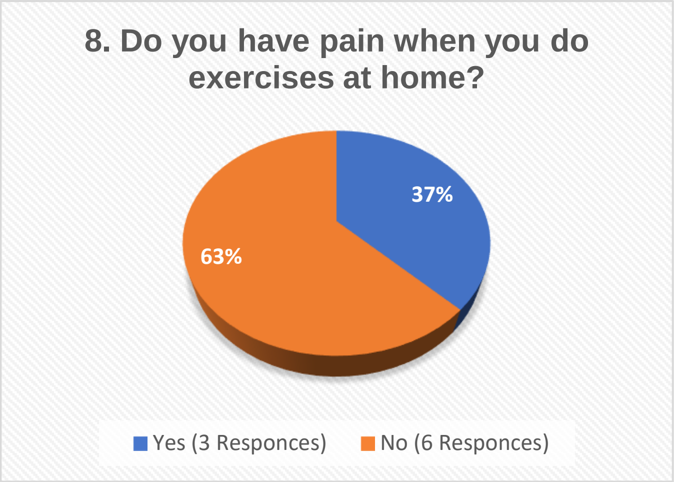
B) Pain management domain

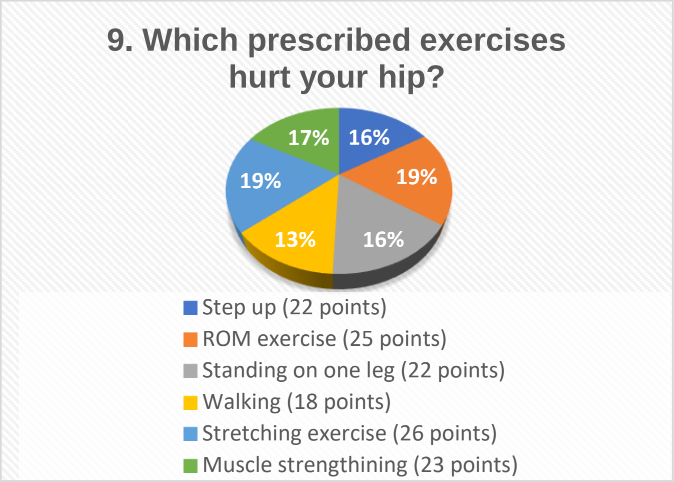
The pain management domain indicates that sitting cross-legged gave the most pain, with a point of 43. Walking and jumping represented the same amount of pain (35 points), and standing on one leg, running, and squatting had scores of 31, 30, and 29, respectively. It seems that all these activities cause a great deal of pain for children with Perthes. The most effective pain relief strategies reported were sleep and ice packs, with eight and six responses, respectively. Taking medication and doing stretching exercises were selected by four and two children with Perthes, respectively. Children had been advised by doctors to avoid certain activities, as follows: trampolining (nine responses), jumping (eight responses), running (six responses), and sitting cross-legged (four responses); no child reported being advised to avoid cycling. Six Children with Perthes reported no pain when they did prescribed exercises at home, while three reported that they did. The levels of pain (points) during prescribed stretching, ROM, and muscle strengthening exercises were reported as 26, 25, and 23, respectively. Pain during "standing on one leg" and step-up exercises were 22 points for pain level, while walking had the lowest pain level, 18 points (questions 5–9).





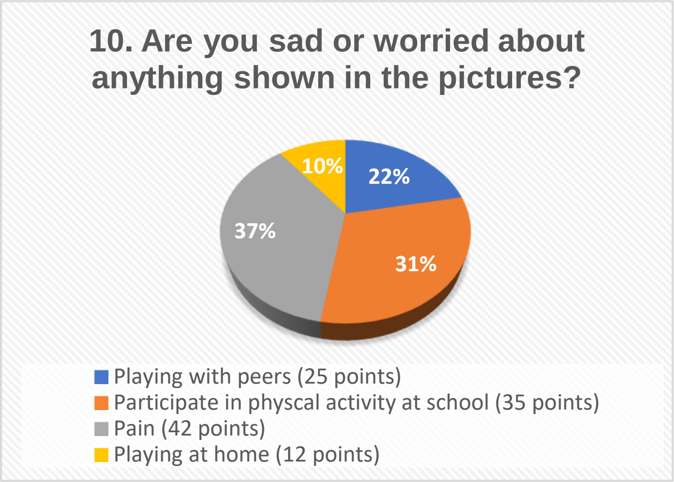






C) Child’s concerns domain

In the domain of concerns, the children with Perthes felt most worried or sad about their pain level and participating in physical activity at school, giving these points of 42 and 35, respectively. Playing with peers and playing at home also worried children with Perthes (points of 25 and 12, respectively) (Question 10).



5.4.8.3c Summary of managing physiotherapy treatment questionnaire

Nine children with Perthes and their parents completed the managing physiotherapy treatment questionnaire. Most of the participants were living in England. One case had a positive Perthes family history. The earliest symptoms noticed by parents were limping and difficulty in walking. Most parents of children with Perthes reported not knowing their child’s Perthes stage. With regard to physiotherapy practice, the vast majority of children with Perthes received physiotherapy treatment at least monthly, and sessions lasted between 30 and 60 minutes; there was one exception. The main objectives of physiotherapy sessions (as reported by parents) were to improve hip movement and increase hip muscle strength. The most common treatments received during physiotherapy sessions were ROM and stretching exercises (as reported by parents). Seven of the nine children with Perthes reported that the physiotherapist had advised them to do exercises at home, including muscle strengthening, ROM, stretching, standing on one leg, walking, and step-up exercises. Half the children with Perthes usually did the exercises at home; the others sometimes did them.

Regarding pain level, sitting cross-legged gave much more pain than other activities (e.g., walking, jumping, standing on one leg, running, and squatting), based on the child questionnaire. All these activities caused children with Perthes great pain. The pain relief strategies of sleeping and applying ice packs were reported as being more effective than taking medication and doing stretching exercises. The activities that doctors had advised children with Perthes to avoid were trampolining, jumping, running, and sitting cross-legged. Most of the children with Perthes reported no pain when they did the prescribed exercises at home. The rest of the children with Perthes who reported pain during prescribed exercises at home found pain level was high in stretching, ROM, and muscle-strengthening exercises. Parents were most concerned about the long-term consequences of Perthes disease, such as surgery; however, mobility, pain management, and the psychological impact of Perthes disease (e.g., anxiety and feeling lonely) worried parents as well. The children with Perthes felt most worried and sad about pain levels, participating in physical activity at school, playing with peers, and playing at home. It seems that both parents and children are significantly worried about managing pain levels.

5.4.8.4 Summary of the results section

The current study's rehabilitation classification stages for children with Perthes were mild (seven children with Perthes) and moderate (two) based on the CLIPer. Passive joint ROM and muscle strength were not statistically significant differences between Perthes legs and the control group (p>0.05). The functional activities showed compensation-movement in temporospatial, kinematic and kinetic data, especially in frontal walking parameters and single-leg balance activity. Data from the questionnaires indicate the following outcomes. The physical activity questionnaire (PAQ-C) shows that the Perthes group spends less time in sports and leisure activities at school and home than controls, but the difference is not statistically significant. Quality of life was significantly lower in the Perthes group than in the controls. This difference in the quality of life might be related to three factors. First, the psychological wellbeing factor gained a significantly lower score in the Perthes group as they felt sad. The second factor relates to the time children have for themselves and the organisation of their leisure time activities. The third factor is a significantly lower score on concentration at school. The managing physiotherapy treatment questionnaires of children with Perthes and their parents showed concern from both parents and children about pain level and the long-term consequences of Perthes disease. It seems that pain levels significantly affect children with Perthes, restricting their activity time at home and/or school and making them sad. In conclusion, the Perthes group displayed compensation mechanisms during three functional activities, especially in the hip joint at a single-limb stance. The children with Perthes and their parents were significantly worried about pain, impacting their quality of life.

5.5 Discussion

5.5.1 Comparison between controls and Perthes group in functional activities data

The present study aimed to compare controls and children with Perthes in three functional activities to identify movement compensation. The dominant leg in the control group and both legs (affected and non-affected) in the Perthes group were considered in this work as (based on the Perthes literature) children with Perthes display differences between legs. This section is divided into four subsections that compare demographic, walking, balance and squat data between control and Perthes groups.

5.5.2 Demographic data

5.5.2.1 Population properties

The present study involved 15 control children and 9 children with Perthes. There was no statistically difference between Perthes and control groups in age, height, body mass and leg length distance. Trendelenburg's sign was observed in two children with Perthes during walking, and five children with Perthes had a positive Thomas test in the hip. The CLIPer results showed seven children with Perthes were at the mild stage, while two were at the moderate stage. The pain was primarily reported after doing single-leg balance by two children with Perthes, and one Perthes child reported pain after clinical examination after walking and squat activities. The control group did not report pain during the whole trial.

The demographic data showed more boys than girls in both groups, by approximately 1.5%. It corresponds to Perry et al.'s (2012) study investigating the prevalence of Perthes disease in the UK, which found that Perthes disease affected more boys than girls at age four to eight years. BMI result indicates that the control and Perthes group had a normal weight. As most children with Perthes in the current study were in the mild stage, Trendelenburg's sign was observed only in two cases. The Thomas test was positive in five children with Perthes.

5.5.2.2 Passive range of motion and muscle strength test

The Perthes group demonstrated no statistically significant difference in passive ROM and muscle strength test compared to the control group. Possibly, the majority of the Perthes participants had a mild form of the disease. The results for passive ROM are in line with Stief et al. (2016) in most parameters, except hip flexion and abduction. Although the passive ROM results are almost the same in this current study and Stief et al. (2016) study, Baker (2013) reports the difficulty of comparing children's physical examination data with data in the literature. Baker (2013) recommends that the researcher create their own normative range of physical examination data for each motion analysis study, including passive ROM and muscle strength test. Thus, the present study included a physical examination to provide a standard (control data) to compare Perthes data.

5.5.3 Walking activity

To compare walking between children with Perthes and typically developing children, temporospatial, kinematic and kinetic parameters were considered in three planes (sagittal, frontal, and transverse).

5.5.3.1 Walking activity: Temporospatial parameters

The control group demonstrated higher gait speed than children with Perthes, reflected in higher temporospatial parameters, except in stance phase and cadence, where parameters were higher in the Perthes group. The Perthes group demonstrated higher values on the non-affected side than the affected side in all temporospatial parameters. However, these differences were not statistically significant between controls and both legs in the Perthes group, except for narrower stride width in the Perthes group than in controls.

An increase in walking speed is reported as the primary outcome influencing temporospatial parameters (Silverman et al. 2008; Begue et al. 2018; Fukuchi et al. 2019). The control group demonstrated a relatively high walking speed in the present study; the other temporospatial parameters had a relatively higher value than those of the Perthes group, except for stance phase and cadence. Diop et al. (2005) and Bovi et al. (2011) report that high walking speed is associated with a short duration of stance phase and lower number of steps in control populations. The current study results are consistent with Perthes literature that found the children with Perthes walked slowly with short stride/step length, and these differences were not statistically significant (Westhoff et al. 2012; Stief et al. 2014; Stief et al. 2016; Karimi et al. 2019). However, no previous Perthes study has considered the stride width parameter, an essential variable to predicate gait stability (Ko et al. 2007). In this study, the control group demonstrated a statistically significantly wide stride width than the Perthes group. This result is similar to Van der Krogt et al. (2014), who found that control subjects walked with wider stride than children with cerebral palsy, who walked faster. There are clear signs in the literature that children with Perthes may have gait instability. Svehlik et al. (2012) and Westhoff et al. (2006) report that children with Perthes spend a relatively prolonged time in the stance phase; this may indicate that children with Perthes try to avoid standing on one leg. The present study discusses postural stability among children with Perthes; additional discussion is presented in the following sections.

5.5.3.2 Walking activity: Sagittal parameters

In this current study, the minimum hip flexion was the only parameter demonstrated statistically significantly lower by approximately 7° in both Perthes legs than control in sagittal kinematic parameters. This reduction of hip extension throughout the gait cycle has been reported by Frigo et al. (1996) as a compensatory mechanism among patients with juvenile chronic arthritis to reduce pain and protect the affected joint. Furthermore, the result of decreased hip extension in this current study is in line with the Perthes literature that found the Perthes group demonstrated a significant reduction in minimum hip flexion by approximately 6° (Westhoff et al. 2012; Stief et al. 2016; Karimi et al. 2019). Unlike the current study result, Westhoff et al. (2012) and Karimi et al. (2019) reported a statistically significant difference between Perthes and control groups in a maximum of trunk posterior tilt and maximum of anterior pelvis tilt. This difference between the current study and Perthes literature in trunk and pelvis tilt may be due to the severity of the Perthes population. For instance, Westhoff et al. (2012) divided children with Perthes into two groups: are florid stage (initial, condensation, fragmentation, reosification) and the advanced stage (reparation, final). The florid stage demonstrated a statistically significant trunk posterior tilt, while the Perthes group in the advanced stage demonstrated no statistically significant difference. In addition, the age of the Perthes population in Karimi et al. (2019) study was relatively higher than the current study by one year difference, and the severity of Perthes disease was fair for all children with Perthes.

Moreover, the kinetic data in this current study showed no statistically significant difference between Perthes and control groups in all parameters. However, the affected Perthes leg generates less ankle power than the non-affected leg. This finding of the current study is in line with the Stevens et al. (2019) study that found the Perthes group presented a statistically significant reduction of ankle power among the Perthes group compared to control due to a decrease in hip extension during walking.

5.5.3.3 Walking activity: Frontal parameters

The frontal kinematic plane is investigated extensively in the Perthes literature as children with Perthes demonstrate Trendelenburg gait due to weakness in the hip abductor muscle (Westhoff et al. 2006; Yoo et al. 2008; Svehlik et al. 2012; Stief et al. 2014; Stief et al. 2016; Karimi et al. 2019). In the present study, the children with Perthes showed deviation in the frontal plane mainly on the affected side, presenting statistically significant less trunk lean toward stance limb, associated with a slight pelvic drop to the stance limb, less hip adduction compared to the non-affected side and the control group. This finding is consistent with most of the Perthes literature. Westhoff et al. (2006) found that children with Perthes presented three types of gait patterns in the frontal plane. Fourteen out of 29 children with Perthes disease showed a normal frontal plane gait pattern. All other patients with Perthes had at least one parameter outside the healthy children's 2-standard deviation range. Westhoff et al. (2006) divided the rest of the children with Perthes into two distinct gait patterns: Trendelenburg and Duchene. Based on Westhoff et al. (2006) classification criteria, all children with Perthes, in this current study, demonstrated a normal frontal plane gait pattern on both affected and non-affected Perthes sides as all parameters were inside the 2-standard deviation- range of the healthy children. This result of this current study is similar to Yoo et al. (2008), Svehlik et al. (2012), Stief et al. (2014) and Karimi et al. (2019), who found that children with Perthes demonstrated pelvic drop towards affected stance limb with hip less adducted in single-leg support phase compared to non-affected (Perthes) side and controls. They reported that children with Perthes demonstrated less hip and pelvis adduction ROM compared to controls. However, the present study finds disagreement with Stief et al. (2016), which include severe Perthes cases that require hip surgery. They found that children with Perthes had significantly greater trunk lean towards the stance limb and increased trunk ROM and less pelvic drop towards the swing limb and lower pelvis ROM than controls.

The kinetic data for the current study showed a statistically significantly higher peak of hip abductor moment in both Perthes legs compared to the control group, while there was no statistically significant difference in the peak of knee abductor moment between Perthes and control groups. This result is similar to that of Westhoff et al. (2006), who report that the Perthes group showed higher hip abductor moment compared to controls due to weakness in the hip abductor muscle. As the current study revealed no statistically significant difference on all lower limb muscle strength in both Perthes legs, further study using electromyography (EMG) is needed to investigate hip abductor muscle activity during walking among children with Perthes to achieve a better understanding.

5.5.3.4 Walking: Transverse parameters

Little attention is given to the transverse plane in the Perthes gait literature. Three out of eight Perthes studies consider this plane (Yoo et al. 2008; Svehlik et al. 2012; Karimi et al. 2019). This transverse plane gives indications about how hip joint deformity can affect lower limb joints. Yoo et al. (2008) investigated the relationship between femoral head deformity and abnormal gait pattern in the transverse plane among children with Perthes, based on location and size of the femoral hump. They found that children with Perthes out-toeing in their walk had an anteriorly deviated femoral hump associated with external rotation of the hip with pelvis rotated internally. In contrast, in-toeing children had a laterally deviated femoral hump associated with internal rotation in the hip with pelvis rotated externally.

In this current study, the Perthes group demonstrated a statistically significant decrease in trunk, pelvis and hip rotation ROM compared to the control group. This result is consistent with the Perthes literature. Karimi et al. (2019) report that children with Perthes demonstrated significantly less rotational ROM of trunk, pelvis and hip joints than controls. Moreover, Yoo et al. (2008) and Svehlik et al. (2012) found that in Perthes subjects, the affected pelvis was internally rotated with the hip externally rotated in unloading Perthes group to avoid femoroacetabular impingement.

Therefore, the Perthes group in this study demonstrated an out-toeing gait pattern, presenting a slight decrease in trunk rotation and internal rotation of the pelvis while the hip rotated externally. This deviation in the transverse plane may aim to reduce joint impingement, which may occur due to the location and size of the femoral hump; it may present as anterior or lateral deviation. Further investigation is needed to confirm that the gait deviation in the transverse plane may be related to femoroacetabular impingement. The following table compares Perthes gait literature and the current study result in the walking data.

5.5.3.5 Comparing Gait outcome between Perthes literature and current study

Table 34: Compared Gait Outcome between Perthes Literature and Current Study

		Gait Outcome	Perthes Literature		Current study result
			Statistically significant difference	No statistically significant difference	
Temporospatial Parameters		Slower Gait speed	Westhoff et al. (2006) Karimi et al. (2019).	Westhoff et al. (2012) Stief et al. (2014) Stief et al. (2016)	Similar to the literature, there was no statistically significant difference.
		Short Stride or Step length	Westhoff et al. (2006)	Westhoff et al. (2012) Karimi et al. (2019). Stief et al. (2016).	Similar to the literature, there was no statistically significant difference.
		Higher Stance phase time	--	Westhoff et al. (2006) Karimi et al. (2019).	Similar to the literature, there was no statistically significant difference.
		Higher cadence in normal Perthes Loading group	--	Svehlik et al. (2012).	Similar to the literature, there was no statistically significant difference.
Kinematic Parameters	Sagittal	Increased Trunk total ROM with significant posterior tilt	Westhoff et al. (2012) Karimi et al. (2019)	Westhoff et al. (2012)	Similar to the literature, there was no statistically significant difference.
		Increase maximum pelvis anterior tilt	Westhoff et al. (2012) Karimi et al. (2019)	--	Similar to the literature, there was no statistically significant difference.
		A significant reduction in maximum hip extension	Stief et al. (2016) Westhoff et al. (2012) Karimi et al. (2019)	--	Similar to the literature, there was a statistically significant difference.
		Decreased hip flexion during the gait cycle	--	--	Different from the literature, the hip flexion increased throughout the gait cycle, but no statistically significant difference.
		Decrease Knee (flexion/extension) ROM	Stief et al. (2016) Westhoff et al. (2012)	--	Different from the literature, the Knee ROM was increased in the affected Perthes leg while reduced in the non-affected leg with no statistically significant difference.
		Decrease Ankle plantar flexion ROM	--	Stevens et al. (2019).	Different from the literature, ankle plantar flexion ROM was increased with no statistically significant difference.
	Frontal	Trunk lean to the stance limb at single stance time	Westhoff et al. (2006), Stief et al. (2016) (Karimi et al. (2019) Stief et al. (2014)).	Westhoff et al. (2006)	Similar to the literature, there was a statistically significant difference.
		Increase pelvic drop to the swinging limb at single stance time	Westhoff et al. (2006), Karimi et al. (2019)	Stief et al. (2014) Svehlik et al. (2012), Stief et al. (2016)	Different from the literature, the pelvis slightly drops to the stance limb with no statistically significant difference.
		Increased hip adduction at single stance time	Westhoff et al. (2006), Karimi et al. (2019)	Svehlik et al. (2012)	Different from the literature, the hip less adducted in affected Perthes leg compared to control with a statistically significant difference.
	Transverse	Lower trunk total ROM	Karimi et al. (2019)	--	Similar to the literature, there was a statistically significant difference.
		Lower Pelvic total ROM	Karimi et al. (2019)	--	Similar to the literature, there was a statistically significant difference.

		Lower Hip total ROM	Karimi et al. (2019)	--	Similar to the literature, there was a statistically significant difference.
		Significant decrease of hip internal rotation in the out-toeing group	Yoo et al. (2008).	--	Similar to the literature, there was a statistically significant difference.
		Significant decrease of external hip rotation in the in-toeing group	Yoo et al. (2008).	--	Similar to the literature, there was a statistically significant difference.
Kinetic Parameters	Moment	Lower Hip extension moment	Karimi et al. (2019).	--	Similar to the literature, the hip extension moment was lower in the affected Perthes leg compared to the non-affected leg with no statistically significant difference.
		The increased peak of Hip abductor Moment	Westhoff et al. (2006) Svehlik et al. (2012) Stief et al. (2014).	--	Similar to the literature, there was a statistically significant difference in both Perthes legs.
		Reduction peak of the Hip abductor moment	Stief et al. (2016). Karimi et al. (2019)	Stief et al. (2014).	Unlike the literature, the current study found that the peak of Hip abductor Moment increased in the Perthes group.
		Increased peak Knee abductor Moment	Stief et al. (2014).	--	Similar to the literature, there was no statistically significant difference in both Perthes legs.
		Reduction peak of Knee abductor moment	Stief et al. (2016).	Stief et al. (2014).	Similar to the literature, there was no statistically significant difference in both Perthes legs.
	Power	Decrease peak of Ankle Power	Stevens et al. (2019).	--	Similar to the literature, there was a statistically significant difference between affected and non-affected Perthes leg.

Key: Blue colour indicates a similar result between Perthes literature and the current study., The green colour indicates a similar partial result between Perthes literature and the current study., The yellow colour indicated different results between Perthes literature and the current study.

5.5.4 Single-leg balance activity

As discussed previously, children with Perthes display compensation during single stance support during walking. Therefore, there is a strong assumption that single-leg balance and squatting will also be affected. This section includes more details and discussion regarding the single-leg balance and squat.

The temporospatial parameters for single-leg balance indicated that the COP area was not a statistically significant difference between both Perthes legs and control groups; however, there was a statistically significant lower of COP velocity in the mediolateral direction on the affected Perthes leg by approximately 1.2 second. The findings of COP parameters are similar to Karimi and Esrafilian (2013) study, which investigated the stability of children Perthes and normal subjects. They found that the Perthes group demonstrated no statistically significant difference in COP parameters in anterior/posterior direction, while the COP in mediolateral direction showed a statistically significant difference. Karimi and Esrafilian (2013) attribute the difference in COP parameters in mediolateral direction to the weakness of muscles surrounding the hip joint and unstable posture in the frontal plane. However, Karimi and Esrafilian (2013) study did not provide information regarding other parameters that might help understand the posture in the frontal plane. Therefore, this current study used kinematic and kinetic parameters to understand postural stability among children with Perthes disease.

In this current study, the kinematic data showed only statistically significantly higher trunk obliquity in non-affected Perthes leg and hip flexion in affected Perthes leg compared to the control group. The non-affected Perthes leg demonstrated a statistically significant lower hip abductor moment peak and a statistically significant increased hip power than the control group. In contrast, the affected Perthes demonstrated a statistically significant higher hip abductor moment peak than the control group. The differences in kinematic data may be responsible for the peak of hip abductor moment result in both Perthes legs.

Increasing trunk obliquity in non-affected Perthes leg may be related to reducing the peak of hip abductor moment as presented in Stief et al. (2014) study. Stief et al. (2014) found that the children with Perthes disease who demonstrated more trunk lean toward stance leg had a lower peak of hip abductor moment by shifting the ground rection vector closer to the hip joint canter to decrease loading of the hip joint. Moreover, the increase in hip flexion during standing on the affected Perthes leg may be related to avoiding pain in the groin area and protecting the affected joint (Frigo et al. 1996) as demonstrated in the sagittal plane of walking. The higher result of hip abductor moment in affected Perthes leg may be related to weakness in hip abductor muscle as two children with Perthes, in this current study, had a positive Trendelenburg’s sign. Although there is a statistically significant higher in hip power in non-affected Perthes leg compared to the control group, this difference is relatively small as presented 0.01 (W/kg) difference and may be due to overcoming the deviation in affected Perthes leg.

5.5.5 Squat activity

Based on Westhoff et al. (2006) study criteria to divide Perthes gait pattern, all children with Perthes, in this current study, demonstrated a normal squat pattern on both affected and non-affected Perthes side as all parameters were inside the 2-standard deviation- range of the healthy children, except in the peak of hip and knee abductor moment. The Perthes group demonstrated a compensation mechanism during the squat activity, mainly at the trunk, pelvis ROM and kinetic parameters. The Perthes group displayed statistically significant higher total trunk and pelvis ROM (obliquity and rotation) than controls. The kinetic data showed that the hip and knee abductor moment's peak was statistically significantly lower in the non-affected Perthes leg compared to the control group. However, the difference in the peak of hip and knee abductor moment in the non-affected Perthes compared to control may be related to compensation-movement in trunk and pelvis obliquity as reported in Stief et al. (2014) study.

5.5.6 Relation of hip joint loading with functional activities

Children with Perthes in the current study developed a compensatory movement to reduce loading on the hip joint due to muscle weakness – which causes great pain – and joint impingement during walking, single-leg balance and squat activities. Abductor muscle moment has been reported as the predominant factor determining loading around the hip joint (Stolk et al. 2001; Plasschaert et al. 2006). There is a positive correlation between increased hip loading and poor clinical outcomes such as pain levels (Plasschaert et al. 2006). Svehlik et al. (2012) observed that some children with Perthes could change gait patterns to reduce the load around the hip joint, while others increased the load on their hips, which was associated with pain. Therefore, this hip abductor moment was considered in the current study to identify the functional activities that cause the most significant load on the hip joint in children with Perthes. Hip abductor moment was highest in non-affected Perthes leg and control during walking activity, while the affected Perthes leg demonstrated higher hip loading during single-leg balance activity. The lowest hip loading has been observed in squat activity among Perthes and control groups. This finding is might related to weakness in the hip abductor muscle as two children with Perthes had a positive Trendelenburg’s sign, and it might be related to pain in the groin area as five children with Perthes had a positive Thomas test that reflects on less hip extension during the whole gait cycle. Therefore, Perthes disease affects functional activities; this may negatively impact the quality of life of children with this disease. The consequences of Perthes disease for children and their parents is discussed in the following section.

5.5.7 Questionnaires: Discussion

This section relates to the second objective of this study: evaluating the physical activity level, quality of life and management of physiotherapy treatment for children with Perthes and their parents. It is divided into two subsections. The first presents a discussion of physical activity (PAQ-C) and quality of life (KIDSCREEN-10) questionnaires, comparing Perthes and control groups. The second discusses the Managing of physiotherapy treatment with children with Perthes and their families questionnaire.

5.5.7.1 Physical activity questionnaire (PAQ-C)

The PAQ-C measures mode, frequency and duration of physical and sedentary activities across all domains over the previous seven days. The mean and standard deviation (SD) of total hours for each domain were calculated for weekdays and weekend days. The results of the PAQ-C demonstrated no statistically significant difference in sports and leisure time activities and activities at school and home between Perthes and control groups. Although the physical activity result demonstrated no statistically significant difference, the Perthes group spent less time in sports activities on weekdays and weekend days than controls, with approximately one hour’s difference. Time spent on leisure time activities was higher by approximately one hour in the Perthes group than in controls during weekdays, while controls spent approximately half an hour more than Perthes subjects on leisure time activities on weekend days. The Perthes group spent half an hour less than the control group on activities at school, and approximately three hours less than the control group on activities at home, on weekdays and weekend days.

There is a link between reduced physical activity level and increased incidence of being overweight and obese (Hills et al. 2011). Generally, the Perthes group, in this current study, spent less time in all activities during weekdays and weekend days than controls, except for leisure time activities during weekdays. This finding may explain the relative increased body mass of Perthes subjects. Neal et al. (2016) did a cohort study including 150 children with Perthes disease. They found 16% of children with Perthes were overweight, and 32% were obese. However, Hailer et al.’s (2014) is the only study evaluating physical activity among children with Perthes; they found that the majority of children with Perthes had moderate or high levels of physical activity. It is in contrast with the results of the current study. Hailer et al. (2014) identified children with Perthes during 1978 and 1995. It is known that there is a considerably increased prevalence of overweight and obesity among children today, who spend less time in physical activity compared to children in the past (Harriger and Thompson

2012). In addition, the doctors' advice could be another factor reducing the physical activity level as the doctors prohibited certain favourite activities such as jumping and running (Palmen et al. 2014). Therefore, the impact of decreased physical activity on quality of life is discussed in the next section.

5.5.7.2 Health-related quality of life (KIDSCREEN-10) questionnaire

The KIDSCREEN-10 questionnaire is used to measure health-related quality of life (HRQoL). The general HRQoL index's T-value was statistically significantly lower in the Perthes group than controls, indicating the Perthes group had a lower quality of life score. The detailed analysis demonstrated that the Perthes group felt fit and powerful, with no statistically significant difference compared to controls. However, the psychological well-being was statistically significantly different between Perthes subjects and controls, as the Perthes group felt sad. There was a statistically significant difference in the Perthes group regarding the time for themselves and the organisation of their leisure time activities. Furthermore, the Perthes group scored statistically significantly lower on school concentration than normal (controls). In general, the Perthes group reported a statistically significant lower score for their general health compared to controls.

The results for quality of life are consistent with Hailer et al.'s (2014) Perthes study and studies of children with chronic conditions (Tsao et al. 2007; Williams and Burnfield 2019). Hailer et al. (2014) investigated the quality of life among 116 children with Perthes disease and found they scored statistically significantly lower than typically developing children. Moreover, Tsao et al. (2007) found a link between anxiety level and quality of life. Children with chronic pain presented high anxiety levels associated with poor mental health and social/educational problems. Williams and Burnfield (2019) evaluated psychological difficulties in children with musculoskeletal problems. They found that children with musculoskeletal problems had more anxiety, depression and behavioural/conduct problems than typically developing children without such conditions. These psychological problems impacted the learning process, development and quality of life, similarly to the current study.

The low scores of the Perthes group for psychological wellbeing, time for themselves, the organisation of their leisure time activities and concentration at school may be due to several factors, including pain, poor sleep quality, absence from school, emotional impact and lack of physical activity, as reported by Leo et al. (2019). The following questionnaire attempts to identify the possible causes of low quality of life and how children with Perthes and their families can manage physiotherapy treatment.

5.5.7.3 Managing physiotherapy treatment questionnaire

This questionnaire has two parts, one for parents of children with Perthes and the other for the children themselves. It is divided into six domains; the results for children with Perthes and their parents are discussed here. The six domains are: demographic, diagnostic, physiotherapy practice, management of physiotherapy treatment, pain management and concerns.

A) Demographic domain

The demographic domain indicates that most participants lived in England (six participants), with one living in Wales and one in the Republic of Ireland. This number of Perthes participants matches Perry et al.’s (2012) study that found England has more Perthes cases than Wales and the Republic of Ireland. There is near equality on the affected side: five subjects with right-side involvement and four with left-side involvement. Regarding the family history of Perthes disease, only one case demonstrated a positive family history; this corresponds with Perry and Hall (2011) and Pavone et al. (2019), who report that there is little evidence for genetic risk as an aetiological factor in Perthes disease.

B) Diagnostic domain

The diagnostic domain indicates that the majority of children with Perthes in this study (five) received the diagnosis at between one and three years of age, while the rest received the diagnosis at less than one year or after three years of age. For the vast majority of children with Perthes in the study (seven), limping was the first symptom of Perthes disease, while for two, it was difficulty in walking, and for one, it was pain level. It is in line with Nelitz et al. (2009), who report that Perthes disease arises in children aged three to seven years, who complain about limping and pain (mainly with physical activity, e.g. walking). Moreover, limping in the hip has been reported as an essential compensatory mechanism to reduce the hip joint's loading and alleviate pain during walking among Perthes populations (Westhoff et al. 2012; Stief et al. 2014). The majority of parents (five) were not sure of the Perthes disease stage of their children, but two reported the stage as mild, one as moderate and one as severe. This lack of information is discussed in Leo et al.’s (2019) study, which found a lack of awareness in parents of children with Perthes related to difficulties obtaining an accurate medical diagnosis from healthcare providers during the early manifestation of Perthes disease.

C) Physiotherapy practice domain

The physiotherapy practice domain describes the experience of clinical practice from the perspective of parents and children. Almost all children with Perthes received physiotherapy treatment; one child did not. Four children with Perthes had monthly physiotherapy sessions; all parents reported that sessions lasted 30 and 60 minutes. Parents said that the main objectives of physiotherapy sessions were to improve hip movement (seven responses) and increase hip muscle strength (five responses). In addition, three parents reported maintaining daily activity as the objective of physiotherapy, and two included the improvement of walking and balance activities. One response named decreasing hip pain as the goal of physiotherapy treatment and improving hip blood flow. The most common treatments received during physiotherapy sessions were ROM exercises (seven responses) and stretching exercises (six responses). Four parents received advice and education during physiotherapy sessions; hydrotherapy was the least common treatment (two responses). Only Brech and Guarnieiro's (2006) study discusses physiotherapy programmes for children with Perthes. In that study, children with Perthes received physiotherapy treatment twice a week for 12 weeks, unlike the children with Perthes in this study, who received physiotherapy once a month. The physiotherapy treatment protocol in Brech and Guarnieiro's (2006) study and findings from the current questionnaire are similar, including stretching and strengthening the involved hip muscle. Brech and Guarnieiro (2006) included balance exercises in the physiotherapy protocol, while responses to the current questionnaire do not report these in physiotherapy sessions. Likewise, advice/education and hydrotherapy were included in physiotherapy sessions in the current study, but not in the Brech and Guarnieiro (2006) study. Seven children with Perthes reported that the doctor advised them to do exercises at home, while two reported no exercise at home. Seven children reported being advised to do muscle-strengthening exercises at home, and six named both ROM and stretching exercises. Three named standing on one leg, and three reported walking and step-up activities as prescribed exercises for home. The home exercises correspond to those in physiotherapy sessions and Brech and Guarnieiro (2006).

D) Management of clinical provider advice domain

The clinical provider advice domain management showed that most children with Perthes frequently did the prescribed physiotherapy exercises at home (reported by four parents). However, according to their parents, two children with Perthes did the exercises occasionally, and two who did them rarely. It seems most of the children with Perthes had strong adherence to home exercise; this might be due to the advice/education element of physiotherapy sessions reported by four parents. This strong adherence to home exercise may explain no statistically significant difference in passive ROM and muscle strength test between Perthes and the control group in this current study. Medina-Mirapeix et al. (2017) found that providing information during clinical sessions, advising on integrating exercise into daily routine, and checking skills and adherence during follow-up enhances the frequency of home exercise for children with disabilities.

E) Pain management domain

Children with Perthes disease often complain of pain in the groin area, especially during long walks and outdoor activities (Nelitz et al. 2009). In the pain management domain, sitting cross-legged had a high pain, presented 43 points. Walking and jumping represented the same amount of pain (35 points), and standing on one leg, running and squatting scored 31, 30 and 29 points, respectively. It seems all these activities cause children with Perthes a great deal of pain. These results are consistent with findings in the Perthes literature that pain limits most children’s ability to participate in normal daily activities such as walking, playing outside and climbing stairs (Brech and Guarnieiro 2006; Nelitz et al. 2009; Leo et al. 2019). The pain relief strategies of sleep and ice packs were reported to be the most effective, with eight and six responses, respectively. Taking medication and doing stretching exercises were reported as being used by four and two children with Perthes, respectively. Coverage in the literature of how children with Perthes disease deal with their pain is limited. Leo et al. (2019) mention painkillers as one way to reduce pain among children with Perthes. Nelitz et al. (2009) recommend non-steroidal anti-inflammatory drugs as pain relief medication in the acute stage, but not the analgesic medication for long-term treatment of Perthes disease. In responses to the current questionnaire, four children with Perthes were taking painkiller medication, while the majority of children with Perthes found sleep and using ice packs were the most effective strategies for relieving pain.

Avoiding specific activities (based on doctors’ advice) is reported in Palmen et al.’s (2014) study to reduce peak impact load on the affected hip. Doctors had advised avoidance of trampolining, jumping, running, and sitting cross-legged to nine, eight, six, and four respondents. There was no restriction on cycling (no responses). Four children with Perthes did not have pain when they did the prescribed exercises at home, while three children did. The pain level during prescribed exercises was listed as highest for stretching, ROM and muscle strengthening exercises (26, 25 and 23 points, respectively). “Standing on one leg” and step-up exercises had the same pain level presented 22 points, while walking had the lowest pain level, 18 points.

F. Concerns domain

Parents reported most concern (four responses) about the long-term consequences of Perthes disease, such as operations. Mobility and pain management were the concerns in second place, with three respondents naming each. The psychological impact of Perthes disease (e.g. anxiety and feeling lonely) was named as a concern by two parents. The children with Perthes were most concerned about pain; they felt most worried or sad about it, giving it 42 points. Participation in physical activity at school was their second-highest concern (35 points). Playing with peers and at home also worried children with Perthes (25 points and 12 points, respectively). The results for children with Perthes and their parents align with Leo et al.'s (2019) study, which interviewed children with Perthes disease and their parents. They found that parents of children with Perthes had considerable concern about how Perthes' disease would impact their children in the long term. The main concern is about long-term effects related to the possibility of a hip replacement operation. In addition, Leo et al. (2019) report a concern from parents of children with Perthes regarding the limping gait that affects most children with Perthes disease and feelings of pain. Children with Perthes disease often complain of pain associated with long walks or doing outdoor activities. Leo et al. (2019) found a strong emotional impact on parents of children with Perthes, similar to the current study. In addition, the children with Perthes in Leo et al.'s (2019) study demonstrated most concern about pain, which limited their ability to participate in normal daily activities such as playing outdoors and impacted their mood.

5.5.7.4 Discussion of the questionnaires

The three questionnaires show that children with Perthes disease experienced less physical activity and lower quality of life, possibly due to pain, doctors' advice, concerns (parental and/or child's) and emotional impact. The pain level was of most concern for both parents and children with Perthes and led to worry about the future implications of the disease, such as surgery. The significant amount of pain may lead children with Perthes to feel anxious and participate less in physical activities, negatively impacting school in increased absence, lack of concentration, and poor sleep quality, as found in the current study and Leo et al. (2019). Pain management is not paid much attention in either physiotherapy sessions or the literature. The only method mentioned in the literature is painkillers, as reported by Leo et al. (2019) and Nelitz et al. (2009). In the current study, the children with Perthes reported using different pain relief strategies. They found sleep and ice packs to be most effective while taking medication, and doing stretching exercises were reported as less effective. Therefore, more research on pain management for children with Perthes is needed to alleviate pain and enhance the quality of life. In addition, Children with Perthes develop pain with physical activity, as reported by Nelitz et al. (2009). Thus, children with Perthes tend to reduce physical activities to avoid pain, which leads to increased body weight, as presented in the current study and similarly in the Perthes literature, where obesity/overweight are manifestations of Perthes disease (Neal et al. 2016).

The second possible cause of reduced physical activity is doctors' advice. Children with Perthes are asked to avoid activities involving huge peak impact load on the affected hip, such as trampolining, jumping and running (Palmen et al. 2014). Although these activities are favourite exercises, which children love to do in their spare time, doctors advise stopping them. Meyerber et al. (2019) and Hurson et al. (2007) found that trampolining is a high-risk activity with the potential for significant orthopaedic fracture. In addition, differences in jumping are evident between overweight and normal-weight children, with less hip and knee flexion and a significant reduction in the hip moment and work in the former (Cowley et al. 2020). This difference between overweight and normal-weight children in jumping might increase the load in the hip joint and cause considerable pain on the weak hip, as presented in children with Perthes. Running has been found to increase the load on foot compared to walking in typically developing children aged between four and ten years (Mesquita et al. 2019). In addition, Ounpuu (1994) reports that injuries associated with running might be due to increased stress mechanisms of the body, including increased velocity, joint ROM, forces, joint moment, joint power and muscle activities, compared to walking.

Because all these activities increase the load on the joints, doctors advise children with Perthes to stop them. The consequences of this among children with Perthes are still unknown; further research in this area would be beneficial to understand how children with Perthes feel and help clinical professionals to enhance their psychological well-being. However, the children with Perthes in the current study had increased weight and spent less time in physical activity compared to the control group. This lack of physical activity may be due to the children with Perthes disease suffering from pain and not knowing what physical activity is suitable for them. Pain management was discussed earlier, and the clinical provider should focus more on enhancing the quality of life for children with Perthes and address parents' concerns.

Regarding physical activities, we found that some activities (such as cycling) did not cause significant amounts of pain. No Perthes child reported pain in using a bicycle for physical activity. Greca et al. (2019) compared cycling to walking in children with normal development aged between 8 and 12 years. They found that cycling had a similar cardiovascular load to walking (i.e. the heart rate is similar). The force and moment on the knee and ankle joints were lower in cycling than in walking. Greca et al. (2019) recommend cycling as a safe exercise suitable for weight management in the child population. It may explain why no children with Perthes reported pain in cycling. More research is needed for children with Perthes to investigate whether cycling is safe for the hip joint and whether it could be recommended as an activity for children with Perthes in their spare time and during physical activity sessions in school. The impact on quality of life for children with Perthes of using a bicycle should be measured to identify the effects of cycling as physical activity on reducing body mass and in enhancing the quality of life. Pickering et al. (2013) investigated the effects of participation in cycling on quality of life among children with cerebral palsy. They found that children with cerebral palsy had improved quality of life, increased social participation, and recommended cycling activities in treatment programmes.

The concerns of children and parents and the emotional impact of Perthes disease could be alleviated by reducing pain levels, providing parents with sufficient information about their children's cases, and answering their questions. This current study found that the majority of parents of children with Perthes did not know their child's stage of Perthes disease. They were greatly concerned about the long-term effects of Perthes disease, such as future surgery. A lack of information was reported in Leo et al.'s (2019) study. We recommend that clinical providers explain to parents and children the nature of the disease and its implications with sufficient information and give them opportunities to ask questions to help reduce their concerns. Geense et al. (2017) found that parents of children with kidney disease were often exhausted and depressed and had low quality of life, which could have a negative effect on their children's health outcomes. They recommend that healthcare providers focus on parents' concerns and manage the child's condition. The emotional impact on parents and children with Perthes is identified in the current study and the Perthes literature: parents felt anxious about their children's future, and children had significantly lower scores (than controls) on psychological well-being factors. Continisio et al. (2020) suggest that chronic disease management, mainly in children, requires an integrated physical and psychological approach to both children with chronic disease and their parents. Their study found a significant amount of stress among parents of children with chronic disease, which was positively correlated to the disease degree of children. They recommend routine psychological support for both children and their parents in disease management. The concerns of children with Perthes and their parents could be resolved by decreasing pain levels, finding safe physical activities such as cycling, providing sufficient medical information and giving time for parents and children to ask questions. To reduce the emotional impact, integrating psychological professionals into the management routine could positively alleviate the stress and anxiety of both children with Perthes and their parents.

5.5.8 Discussion of the links between movement compensation in functional activities and management of physiotherapy questionnaire

In the current study, the children with Perthes demonstrated compensation-movement during three functional activities. The first compensation movement is the postural stability deficit. Children with Perthes demonstrated a statistically significant narrow stride width during walking activity and higher COP area while standing on affected Perthes leg may be due to weakness of hip abductor muscle as two children with Perthes had a positive Trendelenburg's sign as supported by Perthes gait literature (Westhoff et al. 2006; Yoo et al. 2008; Svehlik et al. 2012; Stief et al. 2014; Stief et al. 2016; Karimi et al. 2019). The walking and single-leg balance activities were most affected by Perthes disease as reported by children with Perthes in this current study. Therefore, balance training could be part of rehabilitation to enhance postural stability and avoid further injuries and fractures. Further studies are needed to investigate the balance exercise role in enhancing postural stability among children with Perthes.

Second, children with Perthes showed a statistically significant increase in the hip joint flexion during walking and excessive external rotation movement in the transverse plane during walking and squat activities to avoid pain related to femoroacetabular impingement to protect the affected hip joint. To reduce the pain level that children with Perthes might experience, hot packs, cryotherapy, stretching for flexor hip muscle, and taking medication were recommended as pain management for children with Perthes (Nadler et al. 2004; Nelitz et al. 2009; Leo et al. 2019). In this current study, children with Perthes revealed that sleep and ice packs were the most effective pain management, with eight and six responses, respectively. Taking medication and doing stretching exercises were reported as being used by four and two children with Perthes, respectively. Further research is needed to investigate the most effective pain management for children with Perthes.

Third, children with Perthes demonstrated limited movement in the frontal plane during walking as they showed a statistically significant decrease in the trunk and pelvis obliquity associated with less hip adduction. This limitation movement in the frontal plane may be related to statistically significantly increased the hip abductor moment as a result of the weakness of hip abductor muscle as supported by the following Perthes literature (Westhoff et al. 2006; Yoo et al. 2008; Svehlik et al. 2012; Stief et al. 2014; Stief et al. 2016; Karimi et al. 2019). The possible rehabilitation management to overcome compensation-movement associated with functional activities is to include hip ROM exercise, hip strengthening exercise, aquatic exercise and functional activities training such as gait training.

The hip ROM exercise, hip strengthening exercise, aquatic exercise and gait training are suggested for children with Perthes to improve hip mobility and strength and reduce compensation-movement during functional activities (Brech and Guarnieiro 2006; Children and Medical Center 2011; Catania et al. 2017). The Perthes group in this current study revealed no statistically significant difference in hip ROM and muscle strength compared to the control group. This favourable result may relate to the effective role of physiotherapy management. The management of physiotherapy questionnaire revealed that most children with Perthes attend physiotherapy sessions lasting 30 to 60 minutes at least once a month. These sessions aimed to increase hip movement and strength and maintain daily activity (e.g. walking and balance). Physiotherapy sessions included hip ROM and hip strengthening exercises, hydrotherapy and advice/education. The advice/education included exercises at home, including hip ROM and strengthening exercises and physical activities such as standing on one leg, walking and doing step-up exercises. The children with Perthes had strong adherence to home exercise, which might be due to the advice/education in the physiotherapy sessions. The physiotherapy sessions and home exercises reported by parents and children with Perthes in the management of physiotherapy questionnaire may explain the favourable result of hip ROM and muscle strength among the Perthes group. Similarly, Brech and Guarnieiro (2006) found that physiotherapy management played a significant role in improving hip ROM and muscle strength and mitigating hip joint dysfunction in children with Perthes. Therefore, further research is needed to investigate physiotherapy role that includes hip ROM exercise, hip strengthening exercise, aquatic exercise, and gait training to enhance functional activities.

Finally, the consequences of Perthes disease in this current study have been found to reduce physical activity level and negatively affect the quality of life. The doctor’s advice to avoid certain favourite activities to reduce hip loading, such as jumping and running, could be responsible for increased body weight and lead to poor quality of life, as reported by Palmen et al. (2014). Therefore, finding safe physical activities such as cycling could enhance physical activity level and quality of life, as suggested by Pickering et al. (2013) and Greca et al. (2019). Another important recommendation to enhance the quality of life for both children with Perthes and their parents is to answer their questions and reduce their concerns (Geense et al. 2017; Continisio et al. 2020).

In conclusion, the findings for three functional activities and questionnaires may offer helpful knowledge about the consequences of Perthes disease that might help clinical providers to design an effective rehabilitation protocol to enhance functional activities and prevent further complications such as pain, contracture, and weakness. The following table (35) summarises the clinical implications based on the complications children with Perthes revealed in this current study with possible intervention.

Table 35: Clinical Implication based on compensation-movement during functional activities and questionnaire finding

Compensation	Consequences of compensation	Possible causes	Evidence	Possible intervention
1) Postural stability deficit	1. Narrow stride width (during walking) 2. Higher COP area on standing on affected Perthes leg.	Weakness of hip abductor muscle	Two children with Perthes had a positive Trendelenburg’s sign.	Balance Exercise: A) Double limb stance with the narrowed base on an unstable surface. B) Single limb balance activity. Based on Perthes guideline (Children and Medical Center 2011).
2) Increased flexion of the hip joint	1. Decrease hip extension throughout the gait cycle. 2. Less ankle power generation during walking activity. 3. Increased hip abductor moment during walking and single-leg balance activities.	Restrictipon of hip extension muscle	Five children with Perthes disease had a positive Thomas test.	A) Pain relief: 1) Hot pack for pain with flexor hip stretching (Nadler et al. 2004). 2) Cryotherapy (Nadler et al. 2004). 3) Medication prescribed by a physician (Nelitz et al. 2009; Leo et al. 2019). B) ROM exercise for hip joints in all directions (Brech and Guarnieiro 2006). C) Strengthening Exercises mainly for the hip abductor and extensor muscles (Children and Medical Center 2011). D) Aquatic exercises to improve hip joint mobility and hip muscle strength (Catania et al. 2017) D) Gait training: to reduce compensation-movement and improve walking efficiency (Children and Medical Center 2011).
3) Limited movement in the frontal plane of walking.	Decreased trunk and pelvis obliquity, with less hip adducted.	Weakness of hip abductor muscle	Increased hip abductor moment.	
4) Excessive external rotation movement in the transverse plane of walking and squat activities.	Increased external hip rotation during walking and squat activities.	To avoid the pain that might be related to femoroacetabular impingement.	The Perthes group in this study demonstrated an out-toeing gait pattern, presenting a slight decrease in trunk rotation and internal rotation of the pelvis while the hip rotated externally.	
5)Decrease physical activity level and poor quality of life	Lack of participation in activities.	The clinical providers have prohibited many favourite activities to reduce hip loading, such as jumping and running.	The result of (PAQ-C), KIDSCREEN, and Management of physiotherapy treatment questionnaires	A) Finding safe physical activities such as cycling (Pickering et al. 2013; Greca et al. 2019). B) Alleviate the stress and anxiety of both children with Perthes and their parents by giving them time to ask and answer their questions (Geense et al. 2017; Continisio et al. 2020).

5.6 Conclusion

Non-operative children with Perthes in the current study exhibited movement compensation in walking, single-leg balance and squat activities, mainly on affected Perthes leg. This compensatory movement may occur to alleviate pain and encounter hip abduction weakness and the abnormal shape of the hip joint. The children used different strategies to avoid difficulties during functional activities, such as a flexion on the hip joint, decreased frontal plane movement on the trunk, pelvis and hip, and increased external hip rotation in the transverse plane. As children with Perthes experienced difficulties in functional activities, the amount of time on physical activity reduced compared to typically developing children, especially in school activities. Physical inactivity may be reflected negatively in these children with Perthes and lead to poor quality of life. To enhance physical activity levels and health-related quality of life, the discussion of the managing physiotherapy treatment questionnaire suggested numerous factors that could assist clinical providers when they set treatment plans for children with Perthes. Focusing on pain management, finding safe and enjoyable physical activities (e.g. cycling and water activities) and increasing the number of physiotherapy sessions are essential to increase physical activity levels and quality of life. In addition, providing sufficient information about the nature of Perthes disease, listening to parents'/ children with Perthes's concerns and integrating psychological professionals into the routine of management could be positive measures to decrease emotional effects such as anxiety and stress for parents and children.

Chapter Six: Discussion

6.1 Overview

Legg-Calve-Perthes disease is idiopathic avascular necrosis of the hip joint that affects children. It is characterised by different stages, with the main risk of persistent hip deformation, joint movement dysfunction, and the potential for early osteoarthritis. Pain and limping are the most common manifestations associated with functional activities (Krauspe et al. 1997; Nelitz et al. 2009). There are two options for the management of Perthes disease complications: operative and conservative methods. Physiotherapy plays an essential role in both management methods, targeted at hip mobility and increased hip muscle strength in pre-and post-operative stages (Leroux et al. 2018).

The physiotherapy literature has mainly evaluated Perthes hip in a static position (Brech and Guarnieiro 2006; Logan et al. 2019), while limited information is available on evaluating Perthes hip in a dynamic position. The information on the latter is highly important for understanding the effect of Perthes disease on daily functional activities. In reviewing the literature, walking, single-leg balance, and squatting have been identified as basic daily functional activities that help individuals live independently (Bonnechère et al. 2017; Eken et al. 2017; Pirker and Katzenschlager 2017). Additionally, these functional activities are recommended in Perthes rehabilitation management (Children and Medical Center 2011). However, the compensation of walking is the only activity investigated deeply in the Perthes literature. There is limited information regarding other functional activities (just one study evaluated the single-leg balance among children with Perthes), physical activity levels and quality of life. Therefore, this thesis aimed to develop an improved understanding of the effect of Perthes disease on functional activities, physical activity level and quality of life, and the management of physiotherapy treatment in non-operative children with Perthes. Two studies have been conducted to accomplish thesis goals.

6.1.1 Study One

The objectives of study one, a systematic review, were to investigate the quality of Perthes gait literature, identify the movement-compensation strategies during walking of non-operative children with Perthes and identify knowledge gaps. The quality of Perthes gait literature displayed variations in data quality, with scores ranging from 12 to 17 out of 20 due to limitations on reporting, internal validity, external validity, and power information. Regarding movement-compensation strategies, this systematic review highlighted that children with Perthes walked with obvious Trendelenburg’s sign, including a pelvic drop to the swing limb, with the hip slightly adducted in the single stance phase due to hip abductor muscle weakness. This weakness in the hip abductor muscle is related to increased hip abductor moment, as the hip abductor muscle produces insufficient power to encounter the great GRF responsible for increased hip loading. Therefore, children with Perthes use a variety of strategies to reduce hip loading – reducing gait speed, shortening stride length, prolonging stride time, and decreasing the work around the hip joint.

This systematic review identified three main knowledge gaps. First, there is no evidence available regarding postural stability in these Perthes gait literature. Second, there is limited information regarding the type of biomechanical model, the sampling rate of measurement devices, locations of body-mounted markers, filtering and other data processing methods. Finally, there is no evidence available that has linked the compensation-movement of children with Perthes during functional activities to their physical activity levels and quality of life. Therefore, study two aims to fulfil the systematic review gap.

6.1.2 Study Two

It was evident from the systematic review that a paucity of research has examined compensation-movement in other functional activities. However, there is limited published evidence investigating compensation-movement in other functional activities, and there is no information regarding which functional activities could generate more loading on Perthes hip joint. Despite this lack of evidence, patients with Perthes are advised to reduce specific activities that may increase the load on the hip joint and generate considerable amounts of pain, such as running and jumping (Palmen et al. 2014; Neal et al. 2016). Therefore, the information on hip loading during functional activities is still limited. Nevertheless, the information of functional activities is essential. We still need information that links functional activities with physical activity levels and quality of life to understand how Perthes disease could impact the lives of children with Perthes. Therefore, the objectives of the second study were to identify compensation movement on three functional activities that focus on hip loading and then link the results of the functional activities to physical activity levels and quality of life for children with Perthes.

6.1.3a Movement Compensation Strategies

Three main compensation movements have been observed in the current work that children with Perthes use to overcome Perthes disease complications – a hip flexion movement, reduced frontal plane movement on trunk, pelvis and hip, and increased hip external rotation movement in the transverse plane in the affected Perthes leg. Each of these movements is discussed below.

1) Hip flexion movement

   Children with Perthes in this study demonstrated increased hip flexion movement during walking and single-leg balance activities. These findings align with the Perthes gait literature (Svehlik et al. 2012; Westhoff et al. 2012; Stief et al. 2016; Karimi et al. 2019; Stevens et al. 2019). This hip flexion movement has been noticed as a protective mechanism of the affected joint to reduce joint pain. Frigo et al. (1996) found that patients with juvenile chronic arthritis presented hip flexion, especially at the late stance phase during walking, to reduce pain and protect the joint.

2) Reduced frontal plane movement on trunk, pelvis and hip

   The children with Perthes reduced the frontal plane movement on the trunk, pelvis, and hip due to hip abductor muscle weakness that reflects increased hip abductor moment peak during walking and single-leg balance activities. This result of reduced frontal plane movement is similar to Yoo et al. (2008), Svehlik et al. (2012), Stief et al. (2014) and Karimi et al. (2019), who found that children with Perthes demonstrated pelvic drop towards affected stance limb with hip less adducted in single-leg support phase compared to non-affected (Perthes) side and controls.

3) Increased hip external rotation movement in the transverse plane

   In this study, the children with Perthes demonstrated a statistically significant increase in external hip rotation in the transverse plane during walking and squat activity compared to the control group. This compensation in the transverse plane may avoid the pain related to femoroacetabular impingement. This result of increased hip external rotation in the transverse plane is similar to Yoo et al. (2008) and Svehlik et al. (2012) studies that found that the external hip rotation was noticed in the out-toeing Perthes group.

6.1.3b Hip Loading during Functional Activities

This current study compared hip loading during three functional activities (walking, single leg balance, and squat) to identify which activities significantly impact Perthes hip. The abductor hip moment has been reported as the predominant factor determining loading around the hip joint (Stolk et al. 2001; Plasschaert et al. 2006). There is a positive correlation between increased hip loading and poor clinical outcomes such as pain levels (Plasschaert et al. 2006). Svehlik et al. (2012) observed that some children with Perthes could change gait patterns to reduce the load around the hip joint, while others increased the load on their hips, which was associated with pain. Therefore, this hip abductor moment was considered in the current study to identify which functional activities caused the most significant load on the hip joint in children with Perthes.

It was evident from the findings of this study that hip abductor moment was highest in single leg balance in affected Perthes leg compared to non-affected Perthes leg and control group by approximately 50%. In addition, the walking activity demonstrated a second greatest hip loading on affected Perthes leg compared to non-affected Perthes legs and control by 35%. The lowest hip loading has been observed during squat activities for both Perthes and control groups.

The result of a statistically significant increase the hip loading during single-leg balance and walking activities in the affected Perthes side may be due to standing on one leg. In this current study, the children with Perthes presented a high peak of the hip abduction moment during the single-limb stance phase of the gait cycle. Standing on one leg has been reported as a challenging task that requires children with Perthes to maintain the centre of mass within the base of support (Shumway-Cook and Woollacott 2012). However, the children with Perthes in this research demonstrated poor postural stability in single leg balance and walking activities, as demonstrated by the large COP area and a significantly narrow stride width. It aligns with the findings of Stief et al. (2014) and Stief et al. (2016). These researchers found a significant correlation between the weakness of the hip abductor muscle on increasing hip and knee loading. In addition, Hall et al. (2018), investigating the link between hip loading and severity of pain in people with hip osteoarthritis, identified that patients with great hip pain had a significantly higher hip abduction moment with weaker hip abductor muscle strength, presenting with a significantly slower gait speed compared to the control group. The findings of this study also align with Henriksen et al. (2009). These researchers investigated the role of the glutes medius muscle on the hip and knee joints loading during levels of walking among 15 healthy subjects. Intramuscular injections of hypertonic saline were used to reduce glutes medius muscle function. It was evident from the finding that reduced glutes medius muscle function due to pain leads to increased loads in both hip and knee joints during walking. By contrast, Horsak et al. (2015) found that the hip strengthening programme improves trunk position and decreases joint loading among the children population. Further research is required to investigate the effect of a hip-strengthening programme on reducing hip loading during functional activities for children with Perthes.

6.1.3c Level of physical activity, quality of life and management of physiotherapy treatment

Although the information on functional activities is essential to understand compensation-movement, we still need to understand how this may affect physical activity levels and quality of life for children with Perthes. Shaw et al. (2012) recommended evaluating children’s experiences living with impairments to better understand the disease conditions. In this current study, children with Perthes were found to spend less time in sports and school activities, and they presented a significantly poorer quality of life than the control group. Three possible factors may be responsible for reducing physical activity levels and poor quality of life: pain, concerns (by the parents and/or the child) and emotional impacts.

In this study, the pain level was an obvious manifestation of Perthes disease and was associated with functional activities. The pain led parents to worry about the future implications of the disease, such as the need for surgery. The significant amount of pain, especially during functional activities, led children with Perthes to feel anxious and participate less in physical activities, which negatively impacted school performance (e.g. increased absences, lack of concentration and poor sleep quality) (Leo et al. 2019). Pain management has not received significant attention in the Perthes literature, with pain medication advocated (Leo et al. 2019) and (Nelitz et al. 2009). The findings of this study identified the use of several approaches used by children with Perthes to reduce their pain. It included sleeping, applying ice packs, taking medication, performing stretching exercises and reducing physical activities. These approaches need to be investigated in future research to determine their effectiveness.

The second factor identified in this study, responsible for reducing physical activity levels and poor quality of life, was children and parents' concerns. Most parents of children with Perthes did not know their child’s stage of Perthes disease. This finding of a lack of medical information is in line with that of Leo et al. (2019). These researchers reported that parents of children with Perthes expressed difficulties obtaining accurate medical diagnoses from healthcare providers during the early manifestation of Perthes disease. It is recommended that clinicians explain to parents and children the nature of the disease and its implications and provide sufficient information and the opportunity to ask questions to help reduce their concerns. Although not looking at children with Perthes, Geense et al. (2017) found that parents of children with kidney disease were often exhausted and depressed and had a low quality of life, which could have a negative effect on their children’s health outcomes. These researchers recommended that healthcare providers focus on parents’ concerns and manage the child’s condition.

Finally, the emotional impact was identified as a factor in this study that reduced physical activity levels and quality of life. Parents in the current study felt anxious about their children’s future. They could see that their child was in pain and so less likely to participate in physical activities. Continisio et al. (2020) suggested that the management of chronic diseases, mainly in children, requires an integrated physical and psychological approach to children with the chronic disease and their parents. They found a significant amount of stress among parents of children with chronic diseases, which was positively correlated to the disease level of the children. These researchers recommended routine psychological support for both children and their parents in disease management. Therefore, the concerns of children with Perthes and their parents could be resolved by decreasing pain levels, finding safe physical activities, providing sufficient medical information and giving time for parents and children to ask questions. Moreover, bringing psychology professionals into the routine of pain management could positively alleviate the stress and anxiety of both children with Perthes and their parents. Future research focusing on pain management, rehabilitation programmes, reducing concern, and improving the emotional impact of Perthes disease is needed to enhance physical activity and quality of life.

6.2 Research implications

There are a number of research implications that can be derived from the study findings. First, the systematic review findings suggest that there is a paucity of literature documenting and demonstrating the effects of Perthes disease on lower limb joints such as knee and ankle. Despite gait abnormality in children with Perthes being biomechanically considered in the Perthes walking literature, little attention has been given to kinetic parameters, especially for knee and ankle joints. Kinetic parameters, especially knee adduction moment, provide essential signs to predict knee degeneration and develop suitable therapeutic intervention (Foroughi et al.’s 2009). Previous evidence Westhoff et al. (2006), Svehlik et al. (2012) and Westhoff et al. (2012) recommend performing ’ipsilateral trunk lean’ towards the involved side as an unloading mechanism to reduce the load in the involved hip joint, a suggestion that might result from considering only the hip joint and paying less attention to knee joints, especially knee adduction moment. However, Stief et al. (2014) and Stief et al. (2016) considered knee adduction moment and suggested that ‘ipsilateral trunk lean’ should not be recommended as an unloading mechanism for the hip joint in isolation, but that its potential to cause excess lateral knee joint loading should be considered. Thus, considering all lower limb joints with full biomechanical data in future research may help to provide an appropriate recommendation.

Moreover, this study’s results support the importance of investigating muscle activity around the hip joint during functional activities, especially during gait, using electromyography (EMG) to identify muscle activity during functional activity to provide evidence, which shows weakness in the hip abduction muscle as reported in Nelitz et al. (2009) study. This measurement through manual muscle test has been not considered in the Perthes walking literature. Therefore, there is a need for future work to identify muscle power in static and dynamic positions during functional activities. In addition, there is evidence that the non-operative children with Perthes demonstrated poor postural stability as showed narrow stride width during walking and large COP area during the single-leg balance task. These findings may justify the high incidence rate of fracture and joint dislocation for children with Perthes, as Hailer et al. (2014) reported. It is of value for future research as it highlights the need to investigate stability in walking and postural stability for children with Perthes to lower the incidence of fracture and hip joint dislocation.

Few studies to date have evaluated physical activity level and quality of life among non-operative children with Perthes. In the current study, non-operative children with Perthes had lower physical activity levels and poorer quality of life than controls. The poor quality of life among children with Perthes may be due to spending less time on leisure time activities, participating less in physical activity at school, and pain levels, as presented in the physical activity and quality of life findings. After diagnosis with Perthes disease, patients receive advice to reduce certain physical activities that may increase the load on the hip joint and generate considerable pain, such as running and jumping. These restrictions may prevent patients with Perthes from enjoying leisure time activities and cause increased body weight, impacting their mental and social development (Palmen et al. 2014; Neal et al. 2016). Therefore, future research is needed to consider safe and enjoyable activities and evaluate the relationship between enhancing physical activity levels and quality of life and reduced body mass for non-operative children with Perthes.

6.3 Clinical relevance and implications for clinical practice

The non-operative children with Perthes disease demonstrated compensation-movement during functional activities to overcome complications of Perthes disease such as poor postural stability, pain in the groin area, hip abductor muscle weakness and hip deformity. The clinical practice recommends including balance exercise in the rehabilitation programme to enhance postural stability as Brech and Guarnieiro (2006) and the Cincinnati guideline for managing Legg-Calve Perthes disease (Children and Medical Center 2011).

Moreover, the clinical provider is highly recommended to pay more attention to pain management related to enhancing functional activities performance and reduce both children with Perthes and their parents' anxiety level that related to enhancing the quality of life. There is possible pain management that might help children with Perthes disease to reduce their pain level, such as using a hot pack with flexor hip stretching (Nadler et al. 2004), or using a cold pack (Nadler et al. 2004), and taking medication that prescribed by physicians (Nelitz et al. 2009; Leo et al. 2019). Certain activities (e.g. trampolining, jumping and running) could increase pain in the hip joints of children with Perthes, which leads clinicians to advise against them with these activities increasing load on the hip joint, potentially leading to orthopaedic fracture and dislocation (Ounpuu 1994; Hurson et al. 2007; Palmen et al. 2014; Mesquita et al. 2019; Meyerber et al. 2019; Cowley et al. 2020). However, other activities are reported by children with Perthes in this current study and others literature as safe and enjoyable, such as cycling and swimming (Pickering et al. 2013; Greca et al. 2019). Therefore, clinicians should focus on pain management as part of rehabilitation goal setting, considering different pain relief strategies such as sleep and ice packs, preventing activities that increase the load around the hip joint, suggesting safe activities, and enhancing physical activity levels.

Hip muscle weakness and deformity need to maintain and enhance hip strength and mobility to enhance functional activities and prevent further hip complications such as osteoarthritis (Nelitz et al. 2009). Therefore, ROM exercise for the hip joint in all directions, strengthening hip muscles focusing on hip abductor and extensor muscle, aquatic exercise and gait training may reduce the compensation-movement and improve the efficiency of functional activities (Brech and Guarnieiro 2006; Children and Medical Center 2011; Catania et al. 2017).

With regard to the questionnaire “Managing of physiotherapy treatment with children with Perthes and their families”, the majority of parents of children with Perthes in the current study did not know their children’s Perthes disease stage. They were greatly concerned and felt anxious about the long-term effects of Perthes disease, including surgery. This lack of information is also reported by Leo et al. (2019). Geense et al. (2017) recommend that healthcare providers focus on parents’ concerns and manage the child’s condition. Children with Perthes in this study demonstrated the poor quality of life results. In this regard, Continisio et al. (2020) suggest that managing chronic disease in children requires an integrated physical and psychological approach to both children with chronic disease and their parents. Their study found a significant amount of stress among parents of children with chronic disease, which was positively correlated to the disease degree of children. They recommend that psychological support should be a routine of disease management for both parents and children. Therefore, the recommendation for the clinical provider is to explain to parents and children the nature of the disease, discuss rehabilitation goals and give time for questions to help reduce their concern. In addition, integrating psychological professionals into the routine of management could be another positive factor to reduce stress and anxiety in both Children with Perthes and their parents.

6.4 Study strengths and limitations

A) Strengths

The first strength of this thesis is the systematic review that summarises the published work regarding gait deviation among non-operative children with Perthes. A systematic search was undertaken using five search engines to obtain all relevant articles and avoid selection bias. The two observers reviewing the quality of published Perthes walking literature each have a PhD degree; moreover, they were blinded to each other's results to minimise observer bias.

Adding to the strengths of this thesis, the investigation of the quality of biomechanical movement data by establishing the reliability of marker placing and the reliability of walking parameters between sessions in typically developing children before collecting movement data from the Perthes group.

Another strength of this thesis is the standardised protocol used to collect movement data from children typically developing and with Perthes disease. The participants wore swimsuits and performed functional activities barefoot to minimise errors caused by wearing different clothes and shoes. This thesis tries to fill the knowledge gap by considering postural stability for non-operative children with Perthes during walking and single-leg balance. The evaluation of three functional activities (walking, single-leg balance and squat) and their linking to joint ROM, muscle strength and level of pain is another strong point. In addition, its investigation of physical activity levels, quality of life and management of physiotherapy treatment from the perspectives of children with Perthes and their parents further strengthens this thesis.

B) Limitations

Despite every effort to ensure a robust methodological approach to the work presented in this thesis, three limitations are evident; these will now be discussed.

The first limitation is the power calculation. In the second study, 15 healthy children and 9 non-operative children with Perthes participated as a convenience sample. This limitation in sample size may affect the result of this thesis. However, limitation of sample size was inevitable because of the rarity of Perthes disease, the time constraints of the PhD, limited access to the RCCK lab and the impact of COVID-19 on the recruitment process (five healthy children and three children with Perthes had to cancel their appointments). These challenges were the reasons for employing a convenience sample, which has been advocated in such a situation (as Etikan et al. [2017] state).

The second limitation of this study was that the reliability of the researcher using a manual goniometer and handheld dynamometer to evaluate joint ROM and muscle strength had not been accomplished in this current study. However, the researcher has experience in using the manual goniometer and handheld dynamometer for more than 5 years with cerebral palsy patients.

Although this study measured lower limb muscle strength for typically developing and children with Perthes, the dynamic measurements of muscle activity during functional activities were not evaluated, which is considered a limitation of this study.

6.5 Thesis Conclusion

Little research exists to evaluate movement-compensation during walking, single-leg balance and squat, or level of physical activity, quality of life and management of physiotherapy treatment among non-operative children with Perthes. It is due to the rarity of Perthes disease and the lack of published evidence. Therefore, this thesis has attempted to address these gaps by a) reviewing the quality of published Perthes literature regarding functional activities, b) exploring the biomechanical differences between typically developing children and non-operative children with Perthes in walking, single-leg balance and squat, and differences in the level of physical activity and quality of life. In addition, it has evaluated how non-operative children with Perthes and their parents manage physiotherapy treatment. It is another goal in addressing the knowledge gap.

The current study results revealed that the non-operative children with Perthes demonstrated significant compensation-movement in walking, single-leg balance, squat, level of physical activity, and quality of life compared to typically developing children. The functional activities data indicated differences in temporospatial, kinematic and kinetic parameters in three planes (sagittal, frontal and transverse) among non-operative children with Perthes – mainly on the affected Perthes side – compared to the control group. The temporospatial parameters show that the non-operative children with Perthes demonstrated poor postural instability due to statistically significant narrower stride width with a significantly larger COP area in single leg balance activity. In the three functional activities, the non-operative children with Perthes compensated in their movement in sagittal, frontal and transverse planes to possibly overcome pain, hip abductor muscle weakness and the abnormal shape of the femoral head. They used three different strategies: to perform a hip flexion movement during walking and single-leg balance activities as a protective mechanism to reduce pain and protect the affected hip joint. The second strategy was to reduce frontal plane movement on trunk, pelvis and hip joints during walking and single-leg balance activities due to hip abductor muscle weakness that reflects on increased the peak of hip abductor moment. The last strategy was to perform excessive hip external rotation during walking and squat to avoid hip impingement.

This current study also considered hip abductor moment to identify the functional activities that place the most significant load on the hip joint in non-operative children with Perthes. Hip abductor moment was highest during single-leg balance and waking activities in affected Perthes leg compared to non-affected leg and control group. The affected side in the Perthes group demonstrated the most significant hip loading during this activity as a possible result of hip abductor muscle weakness. Movement compensation during the three functional activities may influence physical activity level and quality of life. Therefore, physical activity level and quality of life were investigated as an aim of this thesis.

The physical activity and quality of life findings show that the non-operative children with Perthes had lower scores than the control group. It seems that pain affected non-operative children with Perthes greatly and made them feel sad and spend less time on activities at home and at school. In addition, their parents expressed concerns about the long-term consequences of Perthes disease for their children and pain levels, as reported in the findings from the managing physiotherapy treatment questionnaire. This questionnaire revealed helpful information for clinical providers to consider in treatment planning. Focusing on pain management, finding safe and enjoyable physical activities (such as cycling and water activities) and increasing the frequency of physiotherapy sessions are essential factors in increasing physical activity level and quality of life. In addition, providing sufficient information about the nature of Perthes disease, listening to parents'/ children with Perthes's concerns and integrating psychological professionals into the routine of management could be positive measures to decrease the emotional impact, such as anxiety and stress, for both children and parents.

In summary, there appears to be significant movement-compensation among non-operative children with Perthes during walking, single-leg balance and squat activities. In addition, the level of physical activity and quality of life was lower in non-operative children with Perthes than in controls. This finding may be due to pain in the groin area, hip abductor muscle weakness and abnormal shape of the femoral head. Therefore, many suggestions are made for clinical providers that might enhance physical activity levels and quality of life and increase adherence to physiotherapy treatment.

6.6 Recommendation

Further research is needed to investigate muscle activity around the hip joint during functional activities, especially during gait, using electromyography to identify muscle power;

significant weakness is shown in the static position. Another recommendation for future research is investigating the effects of balance training on gait stability and postural control to decrease the incidence of fracture and joint dislocation. Moreover, it is essential to investigate the effects of swimming and cycling activities on physical activity levels and quality of life and reduce the body mass for non-operative children with Perthes.

References

Akpinar, E. et al. 2019. Greater trochanter apophysiodesis in Legg-Calve-Perthes disease: Which implant to choose? *Indian Journal of Orthopaedics* 53(4), pp. 548–553. Available at: /pmc/articles/PMC6590009/ [Accessed: 3 August 2021].

Alghamdi, M.A. et al. 2004. Exercise treatment for osteoarthritis disability. *Annals of Saudi Medicine* 24(5), pp. 326–331. Available at: /pmc/articles/PMC6148152/ [Accessed: 15 August 2021].

Alle, L. et al. 2008. Gait characteristics of diabetic patients: A systematic review. *Diabetes/Metabolism Research and Reviews* 24(3), pp. 173–191. Available at: https://pubmed.ncbi.nlm.nih.gov/18232063/ [Accessed: 30 August 2020].

Alt, F. 1967. *Advances in bioengineering and instrumentation. New York: Plenum Press.* New York: Plenum Press.

Van Ancum, J.M. et al. 2019. Gait speed assessed by a 4-m walk test is not representative of daily-life gait speed in community-dwelling adults. *Maturitas* 121, pp. 28–34. Available at: https://pubmed.ncbi.nlm.nih.gov/30704562/ [Accessed: 30 November 2020].

Arnold, A.S. et al. 2007. Contributions of muscles to terminal-swing knee motions vary with walking speed. *Journal of biomechanics* 40(16), pp. 3660–71. Available at: http://www.ncbi.nlm.nih.gov/pubmed/17659289 [Accessed: 1 October 2018].

Aslam, S. and Emmanuel, P. 2010. Formulating a researchable question: A critical step for facilitating good clinical research. *Indian Journal of Sexually Transmitted Diseases* 31(1), pp. 47–50. Available at: /pmc/articles/PMC3140151/ [Accessed: 12 February 2021].

Assaiante, C. et al. 2005. Development of postural control in healthy children: A functional approach. *Neural Plasticity* 12(2–3), pp. 109–118. Available at: https://pubmed.ncbi.nlm.nih.gov/16097479/ [Accessed: 4 December 2020].

Atwater, S.W. et al. 1990. Interrater and Test-Retest Reliability of Two Pediatric Balance Tests. *Physical Therapy* 70(2), pp. 79–87. Available at: https://academic.oup.com/ptj/article/2728632/Interrater [Accessed: 4 December 2020].

Bacon, M.C. et al. 1991. Juvenile rheumatoid arthritis aquatic exercise and lower-extremity function. *Arthritis & Rheumatism* 4(2), pp. 102–105. Available at: https://pubmed.ncbi.nlm.nih.gov/11188589/ [Accessed: 5 July 2020].

Baker, R. 2006. Gait analysis methods in rehabilitation. *Journal of NeuroEngineering and Rehabilitation* 3, p. 4. doi: 10.1186/1743-0003-3-4.

Baker, R. 2013. *Measuring walking: a handbook of clinical gait analysis*. Hilary, H. ed. London: Mac Keith Press.

Baker, R. et al. 2016. Gait analysis : clinical facts. *European journal of physical and rehabilitation medicine* 52(August), pp. 560–574. Available at: http://www.ncbi.nlm.nih.gov/pubmed/27618499 [Accessed: 16 December 2017].

Baker, R. et al. 2018. The conventional gait model - success and limitations. In: *Handbook of Human Motion*. Springer International Publishing, pp. 489–508. Available at: https://link.springer.com/referenceworkentry/10.1007/978-3-319-14418-4_25 [Accessed: 16 August 2021].

Bates, B. 1991. The need for an interdisciplinary curriculum. proceedings. In: *In Third national symposium on teaching kinesiology and biomechanics in sports*. Ames, IA

Bauby, C.E. and Kuo, A.D. 2000. Active control of lateral balance in human walking. *Journal* *of Biomechanics* 33(11), pp. 1433–1440. Available at: https://pubmed.ncbi.nlm.nih.gov/10940402/ [Accessed: 30 November 2020].

Baydogan, S.N. et al. 2015. Effect of Strengthening Versus Balance-Proprioceptive Exercises on Lower Extremity Function in Patients with Juvenile Idiopathic Arthritis. *American Journal of Physical Medicine & Rehabilitation* 94(6), pp. 417–428. Available at: https://journals.lww.com/00002060-201506000-00001 [Accessed: 6 August 2021].

Begue, J. et al. 2018. Influence of gait speed on free vertical moment during walking. *Journal of Biomechanics* 75, pp. 186–190. Available at: http://www.ncbi.nlm.nih.gov/pubmed/29804814 [Accessed: 24 April 2020].

Biddle, S.J.H. et al. 2011. An assessment of self-reported physical activity instruments in young people for population surveillance: Project ALPHA. *The international journal of behavioral nutrition and physical activity* 8, p. 1. Available at: http://www.ncbi.nlm.nih.gov/pubmed/21194492 [Accessed: 4 March 2019].

Birt, L. et al. 2014. Adherence to Home Physiotherapy Treatment in Children and Young People with Joint Hypermobility: A Qualitative Report of Family Perspectives on Acceptability and Efficacy. *Musculoskeletal Care* 12(1), pp. 56–61. Available at: http://doi.wiley.com/10.1002/msc.1055 [Accessed: 10 June 2018].

Bjornson, K.F. and Lennon, N. 2017. *Handbook of Human Motion*. Berlin: Springer International Publishing. doi: 10.1007/978-3-319-30808-1.

Bonnechère, B. et al. 2017. Balance improvement after physical therapy training using specially developed serious games for cerebral palsy children: preliminary results. *Disability and Rehabilitation* 39(4), pp. 403–406. Available at: https://www.tandfonline.com/doi/full/10.3109/09638288.2015.1073373.

Booth, A.T.C. et al. 2018. The efficacy of functional gait training in children and young adults with cerebral palsy: a systematic review and meta-analysis. *Developmental Medicine and Child Neurology* 60(9), pp. 866–883. Available at: https://pubmed.ncbi.nlm.nih.gov/29512110/ [Accessed: 12 November 2021].

Bovi, G. et al. 2011. A multiple-task gait analysis approach: Kinematic, kinetic and EMG reference data for healthy young and adult subjects. *Gait and Posture* 33(1), pp. 6–13. doi: 10.1016/j.gaitpost.2010.08.009.

Brach, J.S. et al. 2007. Gait variability and the risk of incident mobility disability in community-dwelling older adults. *Journals of Gerontology - Series A Biological Sciences and Medical Sciences* 62(9), pp. 983–988. Available at: /pmc/articles/PMC2858390/?report=abstract [Accessed: 30 November 2020].

Brech, G.C. and Guarnieiro, R. 2006. CLINICAL SCIENCES EVALUATION OF PHYSIOTHERAPY IN THE TREATMENT OF LEGG-CALVÉ-PERTHES DISEASE. *CLINICS* 61(6), pp. 521–8. Available at: https://pubmed.ncbi.nlm.nih.gov/17187087/ [Accessed: 6 June 2018].

Burdette, H.L. and Whitaker, R.C. 2005. Resurrecting free play in young children: Looking beyond fitness and fatness to attention, affiliation, and affect. *Archives of Pediatrics and Adolescent Medicine* 159(1), pp. 46–50. Available at: https://jamanetwork.com/journals/jamapediatrics/fullarticle/485902 [Accessed: 4 July 2020].

C-Motion 2019. Tutorial: Building a Conventional Gait Model - Visual3D Wiki Documentation. Available at: https://www.c-motion.com/v3dwiki/index.php/Tutorial:_Building_a_Conventional_Gait_Model [Accessed: 26 January 2022].

Castro, M.P. et al. 2015. The influence of gait cadence on the ground reaction forces and plantar pressures during load carriage of young adults. *Applied Ergonomics* 49, pp. 41–46. Available at: https://pubmed.ncbi.nlm.nih.gov/25766421/ [Accessed: 30 November 2020].

Catania, H. et al. 2017. Physical Exercise and Physical Activity for Children and Adolescents with Juvenile Idiopathic Arthritis: A Literature Review. *Pediatric Physical Therapy* 29(3), pp. 256–260. Available at: https://pubmed.ncbi.nlm.nih.gov/28654499/ [Accessed: 4 July 2020].

Catterall, A. 1971. The natural history of Perthes disease. *J Bone Joint Surg Br*

Cereatti, A. et al. 2007. Propagation of the hip joint centre location error to the estimate of femur vs pelvis orientation using a constrained or an unconstrained approach. *Journal of Biomechanics* 40(6), pp. 1228–1234. Available at: https://pubmed.ncbi.nlm.nih.gov/16876805/ [Accessed: 16 August 2021].

Chambers, C.T. et al. 1999. A comparison of faces scales for the measurement of pediatric pain: children’s and parents’ ratings. *PAIN* 83(1), pp. 25–35. Available at: https://www.sciencedirect.com/science/article/pii/S030439599900086X [Accessed: 24 March 2019].

Children, C. and Medical Center, H. 2011. Evidence-Based Care Guideline for Management of Legg-Calve-Perthes Disease in children aged 3 to 12 years Conservative Management of Legg- Calve-Perthes Disease.

Cho, C. et al. 2016. Treadmill training with virtual reality improves gait, balance, and muscle strength in children with cerebral palsy. *Tohoku Journal of Experimental Medicine* 238(3), pp. 213–218. Available at: https://pubmed.ncbi.nlm.nih.gov/26947315/ [Accessed: 12 November 2021].

Cho, S.H. et al. 2004. Gender differences in three dimensional gait analysis data from 98 healthy Korean adults. *Clinical Biomechanics* 19(2), pp. 145–152. Available at: http://www.ncbi.nlm.nih.gov/pubmed/14967577 [Accessed: 1 October 2018].

Cohen, J. 1992. A power primer. *Psychological Bulletin* 112(1), pp. 155–159. Available at: http://doi.apa.org/getdoi.cfm?doi=10.1037/0033-2909.112.1.155 [Accessed: 7 September 2021].

Cohen, J. 2013. *Statistical Power Analysis for the Behavioral Sciences*. Routledge. Available at: https://www.taylorfrancis.com/books/mono/10.4324/9780203771587/statistical-power-analysis-behavioral-sciences-jacob-cohen [Accessed: 26 August 2021].

Cole, G.K. et al. 1993. Application of the joint coordinate system to three-dimensional joint attitude and movement representation: A standardization proposal. *Journal of Biomechanical Engineering* 115(4), pp. 344–349. Available at: https://pubmed.ncbi.nlm.nih.gov/8309227/ [Accessed: 17 August 2021].

Continisio, G.I. et al. 2020. An investigation on parenting stress of children with cystic fibrosis. *Italian Journal of Pediatrics* 46(1). Available at: https://pubmed.ncbi.nlm.nih.gov/32183848/ [Accessed: 2 July 2020].

Cowley, J.C. et al. 2020. Children who are overweight display altered vertical jump kinematics and kinetics from children who are not overweight. *Pediatric Exercise Science* 32(1), pp. 2–8. Available at: https://pubmed.ncbi.nlm.nih.gov/31476733/ [Accessed: 30 June 2020].

Cuthbert, S.C. and Goodheart, G.J. 2007. On the reliability and validity of manual muscle testing: A literature review. *Chiropractic and Osteopathy* 15. Available at: https://pubmed.ncbi.nlm.nih.gov/17341308/ [Accessed: 1 August 2021].

Davis, R.B. et al. 1991. A gait analysis data collection and reduction technique. *Human*

Movement Science 10(5), pp. 575–587. doi: 10.1016/0167-9457(91)90046-Z.

Davis, R.B. 1997. Reflections on clinical gait analysis. In: *Journal of Electromyography and Kinesiology*. Elsevier, pp. 251–257. doi: 10.1016/S1050-6411(97)00008-4.

Denegar, C.R. and Ball, D.W. 1993. Assessing reliability and precision of measurement: an introduction to intraclass correlation and standard error of measurement. *Journal of Sport Rehabilitation* 2(1), pp. 35–42. Available at: https://journals.humankinetics.com/view/journals/jsr/2/1/article-p35.xml [Accessed: 26 August 2021].

Derrick, T.R. et al. 2020. ISB recommendations on the reporting of intersegmental forces and moments during human motion analysis. *Journal of Biomechanics* 99, p. 109533. doi: 10.1016/j.jbiomech.2019.109533.

Desloovere, K. et al. 2006. How can push-off be preserved during use of an ankle foot orthosis in children with hemiplegia? A prospective controlled study. *Gait and Posture* 24(2), pp. 142–151. Available at: https://pubmed.ncbi.nlm.nih.gov/16934470/ [Accessed: 12 November 2021].

Dicharry, J. 2010. Kinematics and kinetics of gait: From lab to clinic. *Clinics in Sports Medicine* 29(3), pp. 347–364. doi: 10.1016/j.csm.2010.03.013.

Diop, M. et al. 2005. Influence of speed variation and age on ground reaction forces and stride parameters of children's normal gait. *International Journal of Sports Medicine* 26(8), pp. 682–687. Available at: http://www.thieme-connect.de/DOI/DOI?10.1055/s-2004-830382 [Accessed: 28 April 2020].

Donath, L. et al. 2016. Leg and trunk muscle coordination and postural sway during increasingly difficult standing balance tasks in young and older adults. *Maturitas* 91, pp. 60–68. Available at: https://pubmed.ncbi.nlm.nih.gov/27451322/ [Accessed: 22 June 2020].

Donelan, J.M. et al. 2004. Mechanical and metabolic requirements for active lateral stabilization in human walking. *Journal of Biomechanics* 37, pp. 827–835. doi: 10.1016/j.jbiomech.2003.06.002.

Downs, S.H. and Black, N. 1998. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *Journal of epidemiology and community health* 52(6), pp. 377–84. Available at: http://www.ncbi.nlm.nih.gov/pubmed/9764259 [Accessed: 1 October 2018].

Duffy, C.M. et al. 1996. Three-Dimensional Gait Analysis in Spina Bifida. *Journal of Pediatric Orthopaedics* 16(6), pp. 786–791. Available at: https://pubmed.ncbi.nlm.nih.gov/8906653/ [Accessed: 26 January 2022].

Dumurgier, J. et al. 2009. Slow walking speed and cardiovascular death in well functioning older adults: Prospective cohort study. *BMJ (Online)* 339(7731), p. 1187. Available at: http://www.bmj.com/ [Accessed: 11 August 2021].

Eken, M.M. et al. 2020. Intraobserver reliability and construct validity of the squat test in children with cerebral palsy. *Pediatric Physical Therapy* 32(4), pp. 399–403. Available at: https://pubmed.ncbi.nlm.nih.gov/32991569/ [Accessed: 10 December 2020].

Eken, M.M.M. et al. 2017. Squat test performance and execution in children with and without cerebral palsy. *Clinical Biomechanics* 41, pp. 98–105. Available at: http://www.clinbiomech.com/article/S0268003316302261/fulltext [Accessed: 14 December 2017].

Eliks, M. et al. 2017. Does structural leg-length discrepancy affect postural control? Preliminary study. *BMC Musculoskeletal Disorders* 18(1), p. 346. Available at:

http://bmcmusculoskeletdisord.biomedcentral.com/articles/10.1186/s12891-017-1707-x [Accessed: 8 December 2017].

Eve, L. et al. 2006. Extrinsic and intrinsic variation in kinematic data from the gait of healthy adult subjects. *Gait & Posture* 24, pp. S56–S57. doi: 10.1016/j.gaitpost.2006.11.041.

Ewins, D. and Collins, T. 2013. Clinical Gait Analysis. In: *Clinical Engineering: A Handbook for Clinical and Biomedical Engineers*. Elsevier Ltd, pp. 389–406. doi: 10.1016/B978-0-12-396961-3.00025-1.

Fisher, A. et al. 2005. Fundamental movement skills and habitual physical activity in young children. *Medicine and Science in Sports and Exercise* 37(4), pp. 684–688. Available at: https://pubmed.ncbi.nlm.nih.gov/15809570/ [Accessed: 4 December 2020].

Fong, S.S.M. et al. 2012. Taekwondo training speeds up the development of balance and sensory functions in young adolescents. *Journal of Science and Medicine in Sport* 15(1), pp. 64–68. Available at: https://pubmed.ncbi.nlm.nih.gov/21802359/ [Accessed: 4 December 2020].

Fox, J. and Day, R. (Richard J. 2009. *A physiotherapist's guide to clinical measurement*. Elsevier.

Franjoine, M.R. et al. 2010. The performance of children developing typically on the pediatric balance scale. *Pediatric Physical Therapy* 22(4), pp. 350–359. Available at: https://pubmed.ncbi.nlm.nih.gov/21068635/ [Accessed: 4 December 2020].

Franki, I. et al. 2014. A clinical decision framework for the identification of main problems and treatment goals for ambulant children with bilateral spastic cerebral palsy. *Research in Developmental Disabilities* 35(5), pp. 1160–1176. Available at: https://pubmed.ncbi.nlm.nih.gov/24631275/ [Accessed: 12 November 2021].

Frigo, C. et al. 1996. Gait alteration in patients with juvenile chronic arthritis: A computerized analysis. *Journal of Orthopaedic Rheumatology* 9(2), pp. 82–90.

Fritz, S. and Lusardi, M.M. 2009. White Paper: Walking Speed: the Sixth Vital Sign. *Journal of Geriatric Physical Therapy* 32(2), pp. 2–5. Available at: https://digitalcommons.sacredheart.edu/pthms_fac [Accessed: 30 November 2020].

Fukuchi, C.A. et al. 2019. Effects of walking speed on gait biomechanics in healthy participants: A systematic review and meta-analysis. *Systematic Reviews* 8(1), p. 153. Available at: https://systematicreviewsjournal.biomedcentral.com/articles/10.1186/s13643-019-1063-z [Accessed: 24 April 2020].

Gage, J.R. 1991. *Gait Analysis in Cerebral Palsy*. Available at: https://books.google.com.sa/books/about/Gait_Analysis_in_Cerebral_Palsy.html?id=bof4MQEACAAJ&redir_esc=y [Accessed: 2 November 2020].

Gage, J.R. 1995. The clinical use of kinetics for evaluation of pathologic gait in cerebral palsy. *Instructional course lectures* 44, pp. 507–515.

Galloway, A.M. et al. 2020. A systematic review of the non-surgical treatment of Perthes' disease. *Bone & Joint Open* 1(12), pp. 720–730. Available at: /pmc/articles/PMC7750739/ [Accessed: 2 August 2021].

Garra, G. et al. 2010. Validation of the Wong-Baker FACES Pain Rating Scale in Pediatric Emergency Department Patients. *Academic Emergency Medicine* 17(1), pp. 50–54. Available at: http://doi.wiley.com/10.1111/j.1553-2712.2009.00620.x [Accessed: 24 March 2019].

Geense, W.W. et al. 2017. The support needs of parents having a child with a chronic kidney disease: a focus group study. *Child: Care, Health and Development* 43(6), pp. 831–838. Available at: https://pubmed.ncbi.nlm.nih.gov/28547746/ [Accessed: 2 July 2020].

Ghanem, I. et al. 2010. Lateral shelf acetabuloplasty in the treatment of Legg–Calvé–Perthes disease: improving mid-term outcome in severely deformed hips. *Journal of Children's Orthopaedics* 4(1), pp. 13–20. Available at: http://online.boneandjoint.org.uk/doi/10.1007/s11832-009-0216-3 [Accessed: 25 October 2020].

Gigante, C. et al. 2002. Prognostic value of Catterall and Herring classification in Legg-Calvé-Perthes disease: follow-up to skeletal maturity of 32 patients. *Journal of Pediatric Orthopaedics* (22(3)), pp. 345–349. Available at: https://journals.lww.com/pedorthopaedics/Abstract/2002/05000/Prognostic_Value_of_Catterall_and_Herring.15.aspx [Accessed: 6 June 2018].

Goldberger, A.L. et al. 2002. Fractal dynamics in physiology: Alterations with disease and aging. *Proceedings of the National Academy of Sciences of the United States of America* 99(SUPPL. 1), pp. 2466–2472. Available at: https://pubmed.ncbi.nlm.nih.gov/11875196/ [Accessed: 30 November 2020].

Goodfellow, N.A. et al. 2015. Adherence to treatment in children and adolescents with cystic fibrosis: a cross-sectional, multi-method study investigating the influence of beliefs about treatment and parental depressive symptoms. *BMC pulmonary medicine* 15, p. 43. Available at: http://www.ncbi.nlm.nih.gov/pubmed/25927329 [Accessed: 10 June 2018].

Gorton, G.E. et al. 1997. Repeatability of the walking patterns of normal children. *Gait & Posture* 5(2), p. 155. doi: 10.1016/s0966-6362(97)83379-6.

Gouda, M.A. 2015. Common pitfalls in reporting the use of SPSS software. *Medical Principles and Practice* 24(3), p. 300. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5588246/ [Accessed: 30 August 2020].

Greca, J.P. de A. et al. 2019. Biomechanical evaluation of walking and cycling in children. *Journal of Biomechanics* 87, pp. 13–18. Available at: https://pubmed.ncbi.nlm.nih.gov/30799080/ [Accessed: 2 July 2020].

Gribble, P.A. et al. 2004. The Effects of Fatigue and Chronic Ankle Instability on Dynamic Postural Control. *Journal of athletic training* 39(4), pp. 321–329. Available at: http://www.ncbi.nlm.nih.gov/pubmed/15592604 [Accessed: 11 June 2018].

Griffiths, M. and Clegg, M. 1988. *Cerebral Palsy: Problems and Practice*. Available at: https://books.google.com.sa/books/about/Cerebral_Palsy.html?id=BrFNAAAACAAJ&redir_esc=y [Accessed: 2 November 2020].

Guffey, K. et al. 2016. Gait parameters associated with balance in healthy 2- to 4-year-old children. *Gait & posture* 43, pp. 165–9. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0966636215008851 [Accessed: 16 December 2017].

Gupta, S. et al. 2011. Effect of strength and balance training in children with Down's syndrome: A randomized controlled trial. *Clinical Rehabilitation* 25(5), pp. 425–432. Available at: https://pubmed.ncbi.nlm.nih.gov/21059663/ [Accessed: 6 August 2021].

Hadders-Algra, M. 2010. Variation and variability: Key words in human motor development. *Physical Therapy* 90(12), pp. 1823–1837. Available at: https://academic.oup.com/ptj/article/90/12/1823/2737889 [Accessed: 4 December 2020].

Hailer, Y.D. et al. 2012. Legg-Calvé-Perthes disease and the risk of injuries requiring hospitalization. *Acta Orthopaedica* 83(6), pp. 572–576. Available at:

https://pubmed.ncbi.nlm.nih.gov/23043293/ [Accessed: 1 August 2021].

Hailer, Y.D. et al. 2014. Legg-Calvé-Perthes disease: Quality of life, physical activity, and behavior pattern. *Journal of Pediatric Orthopaedics* 34(5), pp. 514–521. Available at: https://pubmed.ncbi.nlm.nih.gov/24787306/ [Accessed: 25 June 2020].

Hailey, D. and Tomie, J.A. 2000. An assessment of gait analysis in the rehabilitation of children with walking difficulties. *Disability and Rehabilitation* 22(6), pp. 275–280. doi: 10.1080/096382800296737.

Hall, M. et al. 2018. Frontal plane hip joint loading according to pain severity in people with hip osteoarthritis. *Journal of Orthopaedic Research* 36(6), pp. 1637–1644. doi: 10.1002/jor.23816.

Van Hamme, A. et al. 2015. Gait parameters database for young children: The influences of age and walking speed. *Clinical Biomechanics* 30(6), pp. 572–577. doi: 10.1016/j.clinbiomech.2015.03.027.

Harold W. Kohl, I. et al. 2013. Physical Activity and Physical Education: Relationship to Growth, Development, and Health. Available at: https://www.ncbi.nlm.nih.gov/books/NBK201497/ [Accessed: 10 June 2018].

Harriger, J.A. and Thompson, J.K. 2012. Psychological consequences of obesity: Weight bias and body image in overweight and obese youth. *International Review of Psychiatry* 24(3), pp. 247–253. Available at: https://pubmed.ncbi.nlm.nih.gov/22724646/ [Accessed: 26 June 2020].

Hausdorff, J.M. et al. 1998. Gait variability and basal ganglia disorders: Stride-to-stride variations of gait cycle timing in Parkinson’s disease and Huntington’s disease. *Movement Disorders* 13(3), pp. 428–437. Available at: https://pubmed.ncbi.nlm.nih.gov/9613733/ [Accessed: 30 November 2020].

Hausdorff, J.M. et al. 2001. Gait variability and fall risk in community-living older adults: A 1-year prospective study. *Archives of Physical Medicine and Rehabilitation* 82(8), pp. 1050–1056. Available at: https://pubmed.ncbi.nlm.nih.gov/11494184/ [Accessed: 30 November 2020].

Hay, J. 1973. *Biomechanics of sports techniques.* NJ: Englewood Cliffs.

Heale, R. and Twycross, A. 2015. Validity and reliability in quantitative studies. *Evidence Based Nursing* 18(3), pp. 66–67. Available at: http://ebn.bmj.com/lookup/doi/10.1136/eb-2015-102129 [Accessed: 14 February 2019].

Hébert, L.J. et al. 2011. Isometric Muscle Strength in Youth Assessed by Hand-held Dynamometry. *Pediatric Physical Therapy* 23(3), pp. 289–299. Available at: http://www.ncbi.nlm.nih.gov/pubmed/21829128 [Accessed: 28 October 2018].

Hébert, L.J. et al. 2015. Hand-Held Dynamometry Isometric Torque Reference Values for Children and Adolescents. *Pediatric physical therapy : the official publication of the Section on Pediatrics of the American Physical Therapy Association* 27(4), pp. 414–23. Available at: http://www.ncbi.nlm.nih.gov/pubmed/26397089 [Accessed: 18 March 2019].

Hefti, F. and Clarke, N.M.P. 2007. The management of Legg-Calvé-Perthes’ disease: Is there a consensus?: A study of clinical practice preferred by the members of the European Paediatric Orthopaedic Society. *Journal of Children’s Orthopaedics* . doi: 10.1007/s11832-007-0010-z.

Henriksen, M. et al. 2009. Experimentally reduced hip abductor function during walking: Implications for knee joint loads. *Journal of Biomechanics* 42(9), pp. 1236–1240. Available at: https://pubmed.ncbi.nlm.nih.gov/19368926/ [Accessed: 28 April 2021].

Herring, J. et al. 1992. The lateral pillar classification of Legg-Calve-Perthes disease. *europepmc.org* . Available at: http://europepmc.org/abstract/med/1552014 [Accessed: 11 June 2018].

Herring, J. et al. 2004. Legg-Calvé-Perthes disease: Part I: Classification of radiographs with use of the modified lateral pillar and Stulberg classifications. *journals.lww.com* . Available at: https://journals.lww.com/jbjsjournal/Abstract/2004/10000/Legg_Calv__Perthes_Disease__Part_I__.1.aspx [Accessed: 11 June 2018].

Hertzog, D. et al. 2019. Sensory modulation, physical activity and participation in daily occupations in young children. *Canadian Journal of Occupational Therapy* 86(2), pp. 106–113. Available at: http://journals.sagepub.com/doi/10.1177/0008417419831403 [Accessed: 4 July 2020].

Hills, A.P. et al. 2011. Physical activity and obesity in children. *British Journal of Sports Medicine* 45(11), pp. 866–870. Available at: https://pubmed.ncbi.nlm.nih.gov/21836171/ [Accessed: 25 June 2020].

Himmelmann, K. et al. 2010. The changing panorama of cerebral palsy in Sweden. X. Prevalence and origin in the birth-year period 1999-2002. *Acta Paediatrica, International Journal of Paediatrics* 99(9), pp. 1337–1343. Available at: https://pubmed.ncbi.nlm.nih.gov/20377538/ [Accessed: 12 November 2021].

Hollman, J.H. et al. 2011. Normative spatiotemporal gait parameters in older adults. *Gait and Posture* 34(1), pp. 111–118. doi: 10.1016/j.gaitpost.2011.03.024.

Horan, S.A. et al. 2014. Lower-limb kinematics of single-leg squat performance in young adults. *Physiotherapy Canada. Physiotherapie Canada* 66(3), pp. 228–33. Available at: http://utpjournals.press/doi/10.3138/ptc.2013-09 [Accessed: 14 December 2017].

Hori, N. et al. 2009. Reliability of performance measurements derived from ground reaction force data during countermovement jump and the influence of sampling frequency. *Journal of Strength and Conditioning Research* 23(3), pp. 874–882. doi: 10.1519/JSC.0b013e3181a00ca2.

Horsak, B. et al. 2015. The effects of a strength and neuromuscular exercise programme for the lower extremity on knee load, pain and function in obese children and adolescents: study protocol for a randomised controlled trial. *Trials* 16(1), p. 586. Available at: http://www.trialsjournal.com/content/16/1/586 [Accessed: 16 March 2021].

Horsak, B. et al. 2019. Effects of a lower extremity exercise program on gait biomechanics and clinical outcomes in children and adolescents with obesity: A randomized controlled trial. *Gait and Posture* 70, pp. 122–129. Available at: https://pubmed.ncbi.nlm.nih.gov/30851623/ [Accessed: 15 August 2021].

Hurson, C. et al. 2007. Pediatric trampoline injuries. *Journal of Pediatric Orthopaedics* 27(7), pp. 729–732. Available at: https://pubmed.ncbi.nlm.nih.gov/17878774/ [Accessed: 30 June 2020].

Hyland, M.E. 1992. A reformulation of quality of life for medical science. *Quality of life research : an international journal of quality of life aspects of treatment, care and rehabilitation* 1(4), pp. 267–72. Available at: http://www.ncbi.nlm.nih.gov/pubmed/1299458 [Accessed: 15 January 2019].

Ismail, A. et al. 1998. Prognosis in Perthes' disease: a comparison of radiological predictors. *J Bone Joint Surg Br 80* 2, pp. 310–314. Available at: http://bjj.boneandjoint.org.uk/content/80-B/2/310.short [Accessed: 11 June 2018].

Jacobs, R. et al. 2004. Lateral shelf acetabuloplasty in the early stage of Legg-Calvé-

Perthes disease with special emphasis on the remaining growth of the acetabulum: A preliminary report. *Journal of Pediatric Orthopaedics Part B* 13(1), pp. 21–28. Available at: https://pubmed.ncbi.nlm.nih.gov/15091254/ [Accessed: 11 November 2021].

Janz, K.F. et al. 2008. Measuring activity in children and adolescents using self-report: PAQ-C and PAQ-A. *Medicine and science in sports and exercise* 40(4), pp. 767–72. Available at: http://www.ncbi.nlm.nih.gov/pubmed/18317366 [Accessed: 6 March 2019].

Kadaba, M.P. et al. 1990. Measurement of lower extremity kinematics during level walking. *Journal of Orthopaedic Research* 8(3), pp. 383–392. Available at: http://www.ncbi.nlm.nih.gov/pubmed/2324857 [Accessed: 29 October 2018].

Kang, H. and Lee, S. 2019. Should we prove the balance of baseline data in randomized controlled trials? *Korean Journal of Anesthesiology* 72(2), pp. 89–90. Available at: /pmc/articles/PMC6458517/ [Accessed: 11 November 2021].

Karimi, M. and Esrafilian, A. 2013. Evaluation of the stability of normal subjects and patients with Perthes and spinal cord injury disorders during short and long periods of time. In: *Prosthetics and Orthotics International*. SAGE Publications Ltd, pp. 22–29. Available at: https://pubmed.ncbi.nlm.nih.gov/22683736/ [Accessed: 1 August 2021].

Karimi, M.T. et al. 2019. Evaluation of the hip joint contact force in subjects with Perthes based on OpenSIM. *Medical engineering & physics* 67, pp. 44–48. Available at: http://www.ncbi.nlm.nih.gov/pubmed/30876816 [Accessed: 27 April 2020].

Karimi, M.T. and McGarry, T. 2012. A Comparison of the Effectiveness of Surgical and Nonsurgical Treatment of Legg-Calve-Perthes Disease: A Review of the Literature. *Advances in Orthopedics* . doi: 10.1155/2012/490806.

Keller, T.S. et al. 1996. Relationship between vertical ground reaction force and speed during walking, slow jogging, and running. *Clinical Biomechanics* 11(5), pp. 253–259. doi: 10.1016/0268-0033(95)00068-2.

Kessler, J.I. and Cannamela, P.C. 2018. What are the demographics and epidemiology of legg-calvé-perthes disease in a large Southern California integrated health system? *Clinical Orthopaedics and Related Research* 476(12), pp. 2344–2350. Available at: /pmc/articles/PMC6259889/?report=abstract [Accessed: 11 December 2020].

Kim, C.J. and Son, S.M. 2014. Comparison of spatiotemporal gait parameters between children with normal development and children with diplegic cerebral palsy. *Journal of Physical Therapy Science* 26(9), pp. 1317–1319. Available at: /pmc/articles/PMC4175228/ [Accessed: 13 November 2021].

Kim, H.K.W. et al. 2011. How much varus is optimal with proximal femoral osteotomy to preserve the femoral head in Legg-Calvé-Perthes disease? *Journal of Bone and Joint Surgery - Series A* 93(4), pp. 341–347. doi: 10.2106/JBJS.J.00830.

Kirtley, C. 2006. *Clinical Gait Analysis: Theory and Practice*. Elsevier Health Sciences. Available at: https://books.google.com/books?id=dF4z51oyTsEC&pgis=1 [Accessed: 9 March 2016].

Ko, S.-U. et al. 2007. Stride Width Discriminates Gait of Side-Fallers Compared to Other-Directed Fallers During Overground Walking. *Journal of Aging and Health* 19(2), pp. 200–212. Available at: http://journals.sagepub.com/doi/10.1177/0898264307299308 [Accessed: 28 April 2020].

Kordi, H. et al. 2016. The effect of strength training based on process approach intervention on balance of children with developmental coordination disorder. *Archivos argentinos de pediatria* 114(6), pp. 526–533. Available at:

http://www.sap.org.ar/docs/publicaciones/archivosarg/2016/v114n6a09e.pdf [Accessed: 16 December 2017].

Kratzenstein, S. et al. 2012. Effective marker placement for functional identification of the centre of rotation at the hip. *Gait and Posture* 36(3), pp. 482–486. doi: 10.1016/j.gaitpost.2012.04.011.

Krauspe, R. et al. 1997. Morbus Perthes. *Springer Science and Media* , pp. 289–302. Available at: https://scholar.google.co.uk/scholar?hl=en&as_sdt=0%2C5&q=Krauspe+R%2C+Raab+P%3A+Morbus+Perthes.+Orthopäde+1997%3B+26%3A+289–302.&btnG= [Accessed: 11 June 2018].

Krautwurst, B.K. et al. 2013. The influence of hip abductor weakness on frontal plane motion of the trunk and pelvis in patients with cerebral palsy. *Research in Developmental Disabilities* 34(4), pp. 1198–1203. doi: 10.1016/j.ridd.2012.12.018.

van der Krogt, M.M. et al. 2015. Kinetic comparison of walking on a treadmill versus over ground in children with cerebral palsy. *Journal of biomechanics* 48(13), pp. 3577–3583. Available at: http://dx.doi.org/10.1016/j.jbiomech.2015.07.046 [Accessed: 26 April 2020].

van der Krogt, M.M.M.M. et al. 2014. Overground versus self-paced treadmill walking in a virtual environment in children with cerebral palsy. 40(4), pp. 587–593. Available at: https://linkinghub.elsevier.com/retrieve/pii/S0966636214006195 [Accessed: 18 November 2019].

Kuo, A.D. and Donelan, J.M. 2010. Dynamic Principles of Gait and Their Clinical Implications. *Physical Therapy* 90(2), pp. 157–174. Available at: https://academic.oup.com/ptj/article/90/2/157/2737752 [Accessed: 30 November 2020].

Laklouk, M.A.R. and Hosny, G.A. 2012. Hinged distraction of the hip joint in the treatment of Perthes disease: Evaluation at skeletal maturity. *Journal of Pediatric Orthopaedics Part B* 21(5), pp. 386–393. Available at: https://pubmed.ncbi.nlm.nih.gov/22713742/ [Accessed: 18 November 2020].

Landis, J.R. and Koch, G.G. 1977. The Measurement of Observer Agreement for Categorical Data. *Biometrics* 33(1), p. 159. doi: 10.2307/2529310.

Larson, A.N. et al. 2012. A Prospective Multicenter Study of Legg-Cal e-Perthes Disease Functional and Radiographic Outcomes of Nonoperative Treatment at a Mean Follow-up of Twenty Years. doi: 10.2106/JBJS.J.01073.

Lehmann, J.F. et al. 1992. Biomechanics of Abnormal Gait. *Physical Medicine and Rehabilitation Clinics of North America* 3(1), pp. 125–138. doi: 10.1016/s1047-9651(18)30668-5.

Leo, D.G. et al. 2019. Perspectives on the Social, Physical, and Emotional Impact of Living With Perthes' Disease in Children and Their Family: A Mixed Methods Study. *Global Pediatric Health* 6, p. 2333794X1983523. Available at: https://pubmed.ncbi.nlm.nih.gov/30993152/ [Accessed: 26 June 2020].

Leroux, J. et al. 2018. Legg-Calvé-Perthes disease. *Orthopaedics & traumatology, surgery & research : OTSR* 104(1S), pp. S107–S112. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1877056817303249 [Accessed: 6 June 2018].

Levangie, P.K. and Norkin, C.C. 2005. *Joint structure and function : a comprehensive analysis*. 4th ed. Philadelphia,PA: F.A. Davis Co. Available at: https://cmc.marmot.org/Record/.b2827068x [Accessed: 6 June 2018].

Lewis, A. 1994. Oppenheim, A. (1992). Questionnaire Design, Interviewing and Attitude

Measurement, London, Pinter. Pp 303. £14.99 paperback, £39.50 hardback. ISBN 185567 0445 (pb), 185567 0437 (hb). *Journal of Community & Applied Social Psychology* 4(5), pp. 371–372. Available at: http://doi.wiley.com/10.1002/casp.2450040506 [Accessed: 11 June 2018].

Lim, Y.P. et al. 2017. Effects of step length and step frequency on lower-limb muscle function in human gait. *Journal of Biomechanics* 57, pp. 1–7. Available at: https://pubmed.ncbi.nlm.nih.gov/28411958/ [Accessed: 30 November 2020].

Lin, X. et al. 2015. Frontal plane kinematics in walking with moderate hip osteoarthritis: Stability and fall risk. *Clinical Biomechanics* 30(8), pp. 874–880. doi: 10.1016/j.clinbiomech.2015.05.014.

van der Linden, M.L. et al. 2002. Kinematic and kinetic gait characteristics of normal children walking at a range of clinically relevant speeds. *Journal of pediatric orthopedics* 22(6), pp. 800–6. Available at: http://www.ncbi.nlm.nih.gov/pubmed/12409911 [Accessed: 1 October 2018].

Logan, L. et al. 2019. Severe bilateral Legg-Calvé-Perthes resolved with pamidronate in combination with casts, physiotherapy and adductor tenotomy: A pictorial essay over 11 years. *BMJ Case Reports* 12(9). Available at: /pmc/articles/PMC6754667/?report=abstract [Accessed: 16 September 2020].

Lu, T.-W. and Chang, C.-F. 2012. Biomechanics of human movement and its clinical applications. *The Kaohsiung Journal of Medical Sciences* 28(2), pp. S13–S25. Available at: https://www.sciencedirect.com/science/article/pii/S1607551X11001835?via%3Dihub [Accessed: 6 June 2018].

Lunn, D.E. et al. 2016. Basic biomechanics of the hip. *Orthopaedics and Trauma* 30(3), pp. 239–246. doi: 10.1016/j.mporth.2016.04.014.

M.M., E. et al. 2016. The squat test is a feasible and valid test to assess muscle endurance in children with cerebral palsy. *Gait and Posture* 49, pp. 241–242. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0966636216304386 [Accessed: 14 December 2017].

Maki, B.E. 1997. Gait changes in older adults: Predictors of falls or indicators of fear? *Journal of the American Geriatrics Society* 45(3), pp. 313–320. Available at: https://pubmed.ncbi.nlm.nih.gov/9063277/ [Accessed: 30 November 2020].

Mani, H. et al. 2019. Development of postural control during single-leg standing in children aged 3–10 years. *Gait and Posture* 68, pp. 174–180. doi: 10.1016/j.gaitpost.2018.11.024.

De Mattos, C. et al. 2014. Comparison of hamstring transfer with hamstring lengthening in ambulatory children with cerebral palsy: further follow-up. *Journal of Children's Orthopaedics* 8(6), pp. 513–520. Available at: http://link.springer.com/10.1007/s11832-014-0626-8.

Mazloumi, S.M. et al. 2014. Evolution in diagnosis and treatment of Legg-Calve-Perthes disease. *Archives of Bone and Joint Surgery* 2(2), pp. 86–92. Available at: http://abjs.mums.ac.irtheonlineversionofthisarticleabjs.mums.ac.ir [Accessed: 18 November 2020].

McGinley, J.L. et al. 2009. The reliability of three-dimensional kinematic gait measurements: A systematic review. *Gait and Posture* 29(3), pp. 360–369. doi: 10.1016/j.gaitpost.2008.09.003.

McGrath, P.A. 1989. Evaluating a child's pain. *Journal of pain and symptom management* 4(4), pp. 198–214. Available at: http://www.ncbi.nlm.nih.gov/pubmed/2691586 [Accessed: 28 October 2018].

McSweeney, S.C. et al. 2020. Reliability and minimum detectable change of measures of gait in children during walking and running on an instrumented treadmill. *Gait and Posture* 75, pp. 105–108. doi: 10.1016/j.gaitpost.2019.10.004.

Meadows, B. and Bowers, R. 2019. Biomechanics of the Hip, Knee, and Ankle. In: *Atlas of Orthoses and Assistive Devices*. Elsevier, pp. 207-215.e1. doi: 10.1016/b978-0-323-48323-0.00018-4.

Menz, H.B. et al. 2003. Age-related differences in walking stability. *Age and Ageing* 32(2), pp. 137–142. Available at: https://pubmed.ncbi.nlm.nih.gov/12615555/ [Accessed: 28 September 2020].

Mesquita, P.R. et al. 2019. Running and walking foot loading in children aged 4–10 years. *Journal of Applied Biomechanics* 35(4), pp. 241–246. Available at: https://pubmed.ncbi.nlm.nih.gov/31034309/ [Accessed: 2 July 2020].

Meyerber, M. et al. 2019. Trampoline injuries compared with other child activities. *Archives de Pediatrie* 26(5), pp. 282–284. doi: 10.1016/j.arcped.2019.05.008.

Mielke, M.M. et al. 2013. Assessing the temporal relationship between cognition and gait: slow gait predicts cognitive decline in the Mayo Clinic Study of Aging. *The journals of gerontology. Series A, Biological sciences and medical sciences* 68(8), pp. 929–37. Available at: http://www.ncbi.nlm.nih.gov/pubmed/23250002 [Accessed: 6 June 2018].

Mitchell, L.E. et al. 2004. Spina bifida. In: *Lancet*. Elsevier B.V., pp. 1885–1895. doi: 10.1016/S0140-6736(04)17445-X.

Miyamoto, Y. et al. 2007. A recurrent mutation in type II collagen gene causes Legg-Calvé-Perthes disease in a Japanese family. *Human Genetics* 121(5), pp. 625–629. Available at: https://pubmed.ncbi.nlm.nih.gov/17394019/ [Accessed: 7 November 2021].

Moreau, N.G. et al. 2016. Effectiveness of rehabilitation interventions to improve gait speed in children with cerebral palsy: Systematic review and Meta-Analysis. *Physical Therapy* 96(12), pp. 1938–1954. Available at: https://pubmed.ncbi.nlm.nih.gov/27313240/ [Accessed: 30 November 2020].

Morgan, P. and McGinley, J. 2014. Gait function and decline in adults with cerebral palsy: a systematic review. *Disability and Rehabilitation* 36(1), pp. 1–9. Available at: http://www.tandfonline.com/doi/full/10.3109/09638288.2013.775359 [Accessed: 20 November 2021].

Mueske, N.M. et al. 2019. Impact of gait analysis on pathology identification and surgical recommendations in children with spina bifida. *Gait and Posture* 67, pp. 128–132. doi: 10.1016/j.gaitpost.2018.10.003.

Muirhead-Allwood, W. and Catterall, A. 1982. The treatment of Perthes' disease. The results of a trial of management. *The Journal of bone and joint surgery. British volume* 64(3), pp. 282–5. Available at: http://www.ncbi.nlm.nih.gov/pubmed/7096392 [Accessed: 6 June 2018].

Murley, G.S. et al. 2009. Effect of foot posture, foot orthoses and footwear on lower limb muscle activity during walking and running: A systematic review. *Gait & Posture* 29(2), pp. 172–187. Available at: http://www.ncbi.nlm.nih.gov/pubmed/18922696 [Accessed: 1 October 2018].

Nadler, S.F. et al. 2004. The Physiologic Basis and Clinical Applications of Cryotherapy and Thermotherapy for the Pain Practitioner. *Cryotherapy and Thermotherapy for the Pain Practitioner 395 Pain Physician* 7(3), pp. 395–399.

Naqvi, U. and Sherman, A. I. 2021. *Muscle Strength Grading*. StatPearls Publishing. Available at: http://www.ncbi.nlm.nih.gov/pubmed/28613779 [Accessed: 4 August 2021].

Neal, D.C. et al. 2016. Prevalence of Obesity in Patients With Legg-Calvé-Perthes Disease. *Journal of the American Academy of Orthopaedic Surgeons* 24(9), pp. 660–665. doi: 10.5435/JAAOS-D-16-00120.

Negarandeh, R. and Beykmirza, R. 2020. Quality assessment in systematic reviews: The importance of choosing the right tools. *Nursing Practice Today* 7(3), pp. 161–162. doi: 10.18502/npt.v7i3.3342.

Nelitz, M. et al. 2009a. Morbus perthes: Diagnostische und therapeutische prinzipien. *Deutsches Arzteblatt* 106(31–32), pp. 517–523. doi: 10.3238/arztebl.2009.0517.

Nelitz, M. et al. 2009b. Perthes disease: current principles of diagnosis and treatment. *Deutsches Arzteblatt international* 106(31–32), pp. 517–23. Available at: https://www.aerzteblatt.de/10.3238/arztebl.2009.0517 [Accessed: 6 June 2018].

Neumann, D.A. 2013. *Kinesiology of the Musculoskeletal System: Foundations for Rehabilitation*. Elsevier Health Sciences. Available at: https://books.google.com/books?id=FeJOAQAAQBAJ&pgis=1 [Accessed: 23 November 2015].

Nolan, L. et al. 2007. Balance control: sex and age differences in 9- to 16-year-olds. *Developmental Medicine & Child Neurology* 47(7), pp. 449–454. doi: 10.1111/j.1469-8749.2005.tb01170.x.

Noonan, K.J. et al. 2003. Interobserver variability of gait analysis in patients with cerebral palsy. *Journal of Pediatric Orthopaedics* 23(3), pp. 279–287. doi: 10.1097/00004694-200305000-00001.

Nussbaumer, S. et al. 2010. Validity and test-retest reliability of manual goniometers for measuring passive hip range of motion in femoroacetabular impingement patients. *BMC Musculoskeletal Disorders* 11(1), p. 194. Available at: http://bmcmusculoskeletdisord.biomedcentral.com/articles/10.1186/1471-2474-11-194 [Accessed: 9 June 2018].

O'Brien, W. 2010. *Application of motor control/motor learning to practice Occupational Therapy for Children* . 6th ed. Missouri, USA: Mosby inc.,. Available at: https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=O'Brien+J%2C+Williams+H.+Application+of+motor+control+%2F+motor+learning+to+practice+Occupational+Therapy+for+Children+6th+ed%2C+Missouri+USA%3A+Mosby+inc.%2C+2010&btnG= [Accessed: 4 December 2020].

Oh-Park, M. et al. 2010. Conventional and robust quantitative gait norms in community-dwelling older adults. *Journal of the American Geriatrics Society* 58(8), pp. 1512–1518. Available at: https://pubmed.ncbi.nlm.nih.gov/20646103/ [Accessed: 30 November 2020].

Oudenhoven, L.M. et al. 2019. How normal is normal: Consequences of stride to stride variability, treadmill walking and age when using normative paediatric gait data. *Gait and Posture* 70, pp. 289–297. doi: 10.1016/j.gaitpost.2019.03.011.

Ounpuu, S. 1994. The biomechanics of walking and running. *Clinics in Sports Medicine* 13(4), pp. 843–863. Available at: https://pubmed.ncbi.nlm.nih.gov/7805110/ [Accessed: 2 July 2020].

Özek, M.M. et al. 2008. *The spina bifida: Management and outcome*. Springer Milan. doi: 10.1007/978-88-470-0651-5.

Palmen, N.K. et al. 2014. Post-operative quality of life in children with severe Perthes disease: differences to matched controls and correlation with clinical function. *Orthopedic Reviews* 6(4). Available at: http://www.pagepress.org/journals/index.php/or/article/view/5567

[Accessed: 6 June 2018].

Pantak, M. 2017. Ground Reaction Forces Generated During Rhythmical Squats as a Dynamic Loads of the Structure. *iopscience.iop.org* 245(2). Available at: https://iopscience.iop.org/article/10.1088/1757-899X/245/2/022053/meta [Accessed: 6 January 2022].

Paterno, M. V. et al. 2010. Biomechanical measures during landing and postural stability predict second anterior cruciate ligament injury after anterior cruciate ligament reconstruction and return to sport. *American Journal of Sports Medicine* 38(10), pp. 1968–1978. Available at: https://pubmed.ncbi.nlm.nih.gov/20702858/ [Accessed: 4 December 2020].

Pau, M. et al. 2015. Relationship between static and dynamic balance abilities in Italian professional and youth league soccer players. *Physical therapy in sport : official journal of the Association of Chartered Physiotherapists in Sports Medicine* 16(3), pp. 236–41. Available at: http://www.ncbi.nlm.nih.gov/pubmed/25869425 [Accessed: 11 June 2018].

Pavone, V. et al. 2019. Aetiology of Legg-Calvé-Perthes disease: A systematic review. *World Journal of Orthopaedics* 10(3), pp. 145–165. Available at: https://pubmed.ncbi.nlm.nih.gov/30918798/ [Accessed: 28 June 2020].

Perry, D.C. et al. 2012. Legg-Calvé-Perthes disease in the UK: Geographic and temporal trends in incidence reflecting differences in degree of deprivation in childhood. *Arthritis and Rheumatism* 64(5), pp. 1673–1679. Available at: https://pubmed.ncbi.nlm.nih.gov/22143958/ [Accessed: 5 June 2018].

Perry, D.C. et al. *The Epidemiology and Etiology of Perthes Disease*. Orthop Clin North Am. 42. Available at: https://pubmed.ncbi.nlm.nih.gov/21742139/ [Accessed: 26 June 2020].

Perry, J. et al. 2010. Gait analysis: normal and pathological function. *The Journal of Bone and Joint Surgery-british* 92, p. 1184. Available at: https://insights.ovid.com/bone-joint-surgery-british-volume/bjuk/2010/08/000/gait-analysis-normal-pathological-function-2nd/30/00004624 [Accessed: 11 June 2018].

Phillips, A. and McClinton, S. 2017. Gait deviations associated with plantar heel pain: A systematic review. *Clinical Biomechanics* 42, pp. 55–64. doi: 10.1016/j.clinbiomech.2016.12.012.

Pickering, D. et al. 2013. ‘Every picture tells a story’: Interviews and diaries with children with cerebral palsy about adapted cycling. *Journal of Paediatrics and Child Health* 49(12), pp. 1040–1044. Available at: https://pubmed.ncbi.nlm.nih.gov/23781924/ [Accessed: 2 July 2020].

Pietrzak, K. et al. 2011. Totalna endoprotezoplastyka stawu biodrowego po chorobie Perthesa. *Chirurgia narzadów ruchu i ortopedia polska* 76(3), pp. 129–133. Available at: https://pubmed.ncbi.nlm.nih.gov/21961264/ [Accessed: 4 August 2021].

Pirker, W. and Katzenschlager, R. 2017. Gait disorders in adults and the elderly. *Wiener klinische Wochenschrift* 129(3–4), pp. 81–95. Available at: http://link.springer.com/10.1007/s00508-016-1096-4 [Accessed: 6 June 2018].

Plasschaert, V.F.P. et al. 2006. Hip abductor function in adults treated for Perthes disease. *Journal of Pediatric Orthopaedics Part B* 15(3), pp. 183–189. Available at: https://pubmed.ncbi.nlm.nih.gov/16601586/ [Accessed: 24 September 2018].

Radzimski, A.O. et al. 2012. Effect of footwear on the external knee adduction moment — A systematic review. *The Knee* 19(3), pp. 163–175. Available at: http://www.ncbi.nlm.nih.gov/pubmed/21733696 [Accessed: 1 October 2018].

Rathinam, C. et al. 2014. Observational gait assessment tools in paediatrics - A systematic review. *Gait and Posture* 40(2), pp. 279–285. doi: 10.1016/j.gaitpost.2014.04.187.

Ravens-Sieberer, U. et al. 2010. Reliability, construct and criterion validity of the KIDSCREEN-10 score: a short measure for children and adolescents' well-being and health-related quality of life. *Quality of Life Research* 19(10), pp. 1487–1500. Available at: http://www.ncbi.nlm.nih.gov/pubmed/20668950 [Accessed: 6 March 2019].

Rich, M.M. and Schoenecker, P.L. 2013. Management of legg-calvé-perthes disease using an a-frame orthosis and hip range of motion: A 25-year experience. *Journal of Pediatric Orthopaedics* 33(2), pp. 112–119. Available at: https://pubmed.ncbi.nlm.nih.gov/23389562/ [Accessed: 18 November 2020].

Richardson, J.T.E. 2011. Eta squared and partial eta squared as measures of effect size in educational research. *Educational Research Review* 6(2), pp. 135–147. doi: 10.1016/j.edurev.2010.12.001.

Ruhe, A. et al. 2010. The test-retest reliability of centre of pressure measures in bipedal static task conditions - A systematic review of the literature. *Gait and Posture* 32(4), pp. 436–445. Available at: https://pubmed.ncbi.nlm.nih.gov/20947353/ [Accessed: 4 December 2020].

Sabharwal, S. and Kumar, A. 2008. Methods for assessing leg length discrepancy. *Clinical orthopaedics and related research* 466(12), pp. 2910–22. Available at: http://link.springer.com/10.1007/s11999-008-0524-9 [Accessed: 28 October 2018].

Salter, R. and Thompson, G. 1984. Legg-Calvé-Perthes disease. The prognostic significance of the subchondral fracture and a two-group classification of the femoral head involvement. *J Bone Joint Surg Am*

Salter, R.B. 1984. The present status of surgical treatment for Legg-Perthes disease. *Journal of Bone and Joint Surgery - Series A* 66(6), pp. 961–966. Available at: https://pubmed.ncbi.nlm.nih.gov/6736099/ [Accessed: 25 October 2020].

Sangeux, M. et al. 2011. Hip joint centre localization: Evaluation on normal subjects in the context of gait analysis. *Gait and Posture* 34(3), pp. 324–328. doi: 10.1016/j.gaitpost.2011.05.019.

Saran, N. et al. 2012. Do femoral or salter innominate osteotomies improve femoral head sphericity in Legg-Calvé-Perthes disease? A meta-analysis pediatrics. In: *Clinical Orthopaedics and Related Research*. Springer New York LLC, pp. 2383–2393. Available at: /pmc/articles/PMC3830109/?report=abstract [Accessed: 18 November 2020].

Saunders, J.B. et al. 1953. The major determinants in normal and pathological gait. *The Journal of bone and joint surgery. American volume* 35 A(3), pp. 543–558. doi: 10.2106/00004623-195335030-00003.

Schmid, S. et al. 2013. Secondary gait deviations in patients with and without neurological involvement: A systematic review. *Gait and Posture* 37(4), pp. 480–493. Available at: https://pubmed.ncbi.nlm.nih.gov/23022156/ [Accessed: 30 August 2020].

Schneider, E. and Chao, E.Y. 1983. Fourier analysis of ground reaction forces in normals and patients with knee joint disease. *Journal of Biomechanics* 16(8), pp. 591–601. doi: 10.1016/0021-9290(83)90109-4.

Schwartz, M.H. et al. 2004. Measurement and management of errors in quantitative gait data. *Gait and Posture* 20(2), pp. 196–203. Available at: https://pubmed.ncbi.nlm.nih.gov/15336291/ [Accessed: 16 August 2021].

Schwartz, M.H. et al. 2008. The effect of walking speed on the gait of typically developing children. *Journal of Biomechanics* 41(8), pp. 1639–1650. Available at: https://pubmed.ncbi.nlm.nih.gov/18466909/ [Accessed: 15 August 2021].

Seyler, T.M. et al. 2008. Botulinum Neurotoxin as a Therapeutic Modality in Orthopaedic Surgery: More Than Twenty Years of Experience. *Journal of Bone and Joint Surgery* 90(Supplement_4), pp. 133–145. Available at: https://journals.lww.com/00004623-200811004-00014 [Accessed: 9 November 2021].

Sharma, L. et al. 2000. The mechanism of the effect of obesity in knee osteoarthritis: The mediating role of malalignment. *Arthritis & Rheumatism* 43(3), p. 568. Available at: http://www.ncbi.nlm.nih.gov/pubmed/10728750 [Accessed: 4 October 2018].

Shaw, J.A. et al. 2012. Phenomenology and physiotherapy: meaning in research and practice. *Physical Therapy Reviews* 3196. Available at: http://www.tandfonline.com/doi/full/10.1179/1743288X12Y.0000000043.

Shumway-Cook, A. and Woollacott, M. 2012. *Motor Control: Translating Research into Clinical Practice*. London: Lippincott Williams & Wilkins. Available at: https://www.amazon.com/Motor-Control-Translating-Research-Clinical/dp/1608310183 [Accessed: 4 December 2020].

Silverman, A.K. et al. 2008. Compensatory mechanisms in below-knee amputee gait in response to increasing steady-state walking speeds. *Gait and Posture* 28(4), pp. 602–609. doi: 10.1016/j.gaitpost.2008.04.005.

Simic, M. et al. 2010. Gait modification strategies for altering medial knee joint load: A systematic review. *Arthritis Care & Research* 63(3), p. n/a-n/a. Available at: https://onlinelibrary.wiley.com/doi/10.1002/acr.20380 [Accessed: 20 November 2021].

Song, K. 2011. *Orthopaedic Knowledge Update: Pediatrics 4. Rosemont*. Available at: https://books.google.com.sa/books/about/Orthopaedic_Knowledge_Update.html?id=ghiUnQEACAAJ&redir_esc=y [Accessed: 18 November 2020].

Springer, S. and Khamis, S. 2017. Effects of functional electrical stimulation on gait in people with multiple sclerosis – A systematic review. *Multiple Sclerosis and Related Disorders* 13, pp. 4–12. doi: 10.1016/j.msard.2017.01.010.

Steinwender, G. et al. 2000. Intrasubject repeatability of gait analysis data in normal and spastic children. *Clinical Biomechanics* 15(2), pp. 134–139. doi: 10.1016/S0268-0033(99)00057-1.

Stepanovich, M. et al. 2017. Advanced Containment With Triple Innominate Osteotomy in Legg-Calve-Perthes Disease. *Journal of Pediatric Orthopaedics* 37(8), pp. 563–569. Available at: http://insights.ovid.com/crossref?an=01241398-201712000-00010 [Accessed: 8 December 2017].

Stevens, W.R. et al. 2018. Automated event detection algorithm for two squatting protocols. *Gait and Posture* 59(May 2017), pp. 253–257. Available at: http://dx.doi.org/10.1016/j.gaitpost.2017.10.025 [Accessed: 24 June 2020].

Stevens, W.R. et al. 2019. Compensatory sagittal plane ankle gait mechanics: Are they present in patients with a weak or stiff hip? *Gait and Posture* 74, pp. 250–254. doi: 10.1016/j.gaitpost.2019.09.018.

Stief, F. et al. 2014. Effect of compensatory trunk movements on knee and hip joint loading during gait in children with different orthopedic pathologies. *Gait and Posture* 39(3), pp. 859–864. Available at: https://pubmed.ncbi.nlm.nih.gov/24387803/ [Accessed: 17 January 2021].

Stief, F. et al. 2016. Development of gait performance and dynamic hip and knee joint loading after containment improving surgery in patients with Legg-Calvé-Perthes disease. *Gait & posture* 47, pp. 51–6. Available at: http://www.ncbi.nlm.nih.gov/pubmed/27264403 [Accessed: 8 December 2017].

Stolk, J. et al. 2001. Hip-joint and abductor-muscle forces adequately represent in vivo loading of a cemented total hip reconstruction. *Journal of biomechanics* 34(7), pp. 917–26. Available at: http://www.ncbi.nlm.nih.gov/pubmed/11410175 [Accessed: 24 September 2018].

Stolze, H. et al. 1998. Retest reliability of spatiotemporal gait parameters in children and adults. 7(2), pp. 125–130. Available at: https://linkinghub.elsevier.com/retrieve/pii/S096663629700043X [Accessed: 24 April 2020].

Sussman, M.D. 2010. J. R. Gage, M. H. Schwartz, S. E. Koop, T. F. Novacheck (eds): The identification and treatment of gait problems in cerebral palsy. *Journal of Children's Orthopaedics* 4(2), pp. 177–178. Available at: /pmc/articles/PMC2839865/ [Accessed: 12 November 2021].

Sutherland, D.H. et al. 1980. The development of mature gait. *The Journal of bone and joint surgery. American volume* 62(3), pp. 336–53. Available at: http://www.ncbi.nlm.nih.gov/pubmed/7364807 [Accessed: 1 October 2018].

Svehlik, M. et al. 2012. Pathological gait in children with Legg-Calve-Perthes disease and proposal for gait modification to decrease the hip joint loading. *International orthopaedics* 36(6), pp. 1235–1241. Available at: http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=med7&NEWS=N&AN=22134707.

Taherdoost, H. 2016. Validity and Reliability of the Research Instrument; How to Test the Validation of a Questionnaire/Survey in a Research. *SSRN Electronic Journal* . Available at: https://www.ssrn.com/abstract=3205040 [Accessed: 14 February 2019].

Taylor, W.R. et al. 2005. On the influence of soft tissue coverage in the determination of bone kinematics using skin markers. *Journal of Orthopaedic Research* 23(4), pp. 726–734. doi: 10.1016/j.orthres.2005.02.006.

Tesio, L. et al. 2017. Gait analysis on force treadmill in children: Comparison with results from ground-based force platforms. *International Journal of Rehabilitation Research* 40(4), pp. 315–324. doi: 10.1097/MRR.0000000000000243.

Testa, M.A. and Simonson, D.C. 1996. Assessment of Quality-of-Life Outcomes. *New England Journal of Medicine* 334(13), pp. 835–840. Available at: http://www.nejm.org/doi/abs/10.1056/NEJM199603283341306 [Accessed: 15 January 2019].

Tracy, J.B. et al. 2019. Dynamic stability during walking in children with and without cerebral palsy. *Gait and Posture* 72, pp. 182–187. doi: 10.1016/j.gaitpost.2019.06.008.

Tsao, J.C.I. et al. 2007. Anxiety Sensitivity and Health-Related Quality of Life in Children With Chronic Pain. *Journal of Pain* 8(10), pp. 814–823. Available at: https://pubmed.ncbi.nlm.nih.gov/17613277/ [Accessed: 25 June 2020].

Tsegaw, G. 2014. THE ROLE OF BIOMECHANICAL APPLICATIONS IN MUASCULOSKELETAL AND NEUROLOGICAL REHABILITATION: REVIEW ARTICLE. *Abhinav National Monthly Refereed Journal of Research in Science and Technology* . Available at: https://www.researchgate.net/publication/323545376_THE_ROLE_OF_BIOMECHANICAL_APPLICATIONS_IN_MUASCULOSKELETAL_AND_NEUROLOGICAL_REHABILITATION_REVIEW_ARTICLE [Accessed: 23 October 2021].

Tsushima, H. et al. 2003. Test-retest reliability and inter-tester reliability of kinematic data from a three-dimensional gait analysis system. *Journal of the Japanese Physical Therapy Association = Rigaku ryoho* 6(1), pp. 9–17. doi: 10.1298/jjpta.6.9.

Ugalde, V. et al. 2015. Single leg squat test and its relationship to dynamic knee valgus and injury risk screening. *PM & R : the journal of injury, function, and rehabilitation* 7(3), pp. 229–35; quiz 235. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1934148214007321 [Accessed: 14 December 2017].

Verghese, J. et al. 2007. Quantitative gait dysfunction and risk of cognitive decline and dementia. *Journal of Neurology, Neurosurgery and Psychiatry* 78(9), pp. 929–935. Available at: /pmc/articles/PMC1995159/?report=abstract [Accessed: 28 September 2020].

Villet, L. and Laville, J.-M. 2003. [Shelf acetabuloplasty in Legg-Perthes-Calve disease]. *La butee osteoplastique dans l'osteochondrite primitive de la hanche.* 89(3), pp. 234–241. Available at: http://www.ncbi.nlm.nih.gov/pubmed/12844047 [Accessed: 8 December 2017].

Voss, C. et al. 2017. Validity and reliability of the Physical Activity Questionnaire for Children (PAQ-C) and Adolescents (PAQ-A) in individuals with congenital heart disease. Buchowski, M. ed. *PLOS ONE* 12(4), p. e0175806. Available at: http://www.ncbi.nlm.nih.gov/pubmed/28445485 [Accessed: 29 November 2018].

Wagenaar, R.C. and van Emmerik, R.E.A. 1994. Dynamics of pathological gait. *Human Movement Science* 13(3–4), pp. 441–471. Available at: https://www.sciencedirect.com/science/article/pii/0167945794900493 [Accessed: 1 October 2018].

Waldenström, H. 1922. The defintive forms of coxa plana. *Act Radiol*

Walter, S.D. et al. 1998. Sample size and optimal designs for reliability studies. *Statistics in Medicine* 17(1), pp. 101–110. Available at: https://pubmed.ncbi.nlm.nih.gov/9463853/ [Accessed: 27 August 2021].

Weeks, B.K. et al. 2015. Effect of sex and fatigue on single leg squat kinematics in healthy young adults. *BMC musculoskeletal disorders* 16(1), p. 271. Available at: http://bmcmusculoskeletdisord.biomedcentral.com/articles/10.1186/s12891-015-0739-3 [Accessed: 14 December 2017].

Wessel, J. et al. 1999. Isometric strength measurements in children with arthritis: Reliability and relation to function. *Arthritis & Rheumatism* 12(4), pp. 238–246. Available at: http://doi.wiley.com/10.1002/1529-0131%28199908%2912%3A4%3C238%3A%3AAID-ART2%3E3.0.CO%3B2-I [Accessed: 19 March 2019].

Westhoff, B. et al. 2003. Ultrasound-guided botulinum toxin injection technique for the iliopsoas muscle. *Developmental Medicine and Child Neurology* 45(12), pp. 829–832. Available at: https://pubmed.ncbi.nlm.nih.gov/14667075/ [Accessed: 31 July 2021].

Westhoff, B. et al. 2006. Computerized gait analysis in Legg Calve Perthes disease--analysis of the frontal plane. *Gait & posture* 24(2), pp. 196–202. Available at: http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=med5&NEWS=N&AN=16226031.

Westhoff, B. et al. 2012a. Computerized gait analysis in Legg-Calvé-Perthes disease--analysis of the sagittal plane. *Gait & posture* 35(4), pp. 541–6. doi: 10.1016/j.gaitpost.2011.11.020.

Westhoff, B. et al. 2012b. Computerized gait analysis in Legg–Calvé–Perthes disease—Analysis of the sagittal plane. *Gait & Posture* 35(4), pp. 541–6. doi: 10.1016/j.gaitpost.2011.11.020.

Whiting, P. et al. 2017. A proposed framework for developing quality assessment tools. *Systematic Reviews* 6(1), p. 204. Available at: http://systematicreviewsjournal.biomedcentral.com/articles/10.1186/s13643-017-0604-6

[Accessed: 20 November 2021].

WHO 2000. Obesity: preventing and managing the global epidemic. Report of a WHO consultation. *World Health Organization - Technical Report Series* 894. Available at: https://pubmed.ncbi.nlm.nih.gov/11234459/ [Accessed: 10 September 2021].

Wiig, O. et al. 2008. Prognostic factors and outcome of treatment in Perthes' disease. *The Journal of Bone and Joint Surgery. British volume* 90-B(10), pp. 1364–1371. Available at: http://www.ncbi.nlm.nih.gov/pubmed/18827249 [Accessed: 9 June 2018].

Wilken, J.M. et al. 2012. Reliability and minimal detectible change values for gait kinematics and kinetics in healthy adults. *Gait and Posture* 35(2), pp. 301–307. Available at: https://pubmed.ncbi.nlm.nih.gov/22041096/ [Accessed: 24 April 2020].

Williams, J.J. et al. 1993. Late knee problems in Myelomeningocele. *Journal of Pediatric Orthopaedics* 13(6), pp. 701–703. Available at: https://pubmed.ncbi.nlm.nih.gov/8245190/ [Accessed: 21 November 2021].

Williams, N.A. and Burnfield, J.M. 2019. Psychological difficulties and parental well-being in children with musculoskeletal problems in the 2011/2012 National Survey of Children's Health. *Rehabilitation Psychology* 64(1), pp. 87–97. Available at: https://pubmed.ncbi.nlm.nih.gov/30299139/ [Accessed: 25 June 2020].

Winter, D.A. 2009. *Biomechanics and Motor Control of Human Movement*. Hoboken, NJ, USA: John Wiley & Sons, Inc. Available at: http://doi.wiley.com/10.1002/9780470549148 [Accessed: 17 August 2021].

Wurm, B.J. et al. 2010. *GROUND REACTION FORCE AND RATE OF FORCE DEVELOPMENT DURING LOWER BODY RESISTANCE TRAINING EXERCISES*. Available at: https://ojs.ub.uni-konstanz.de/cpa/article/view/4498 [Accessed: 6 January 2022].

Yang, F. and Pai, Y.C. 2014. Can stability really predict an impending slip-related fall among older adults? *Journal of Biomechanics* 47(16), pp. 3876–3881. Available at: /pmc/articles/PMC4469383/?report=abstract [Accessed: 30 November 2020].

Yentes, J.M. et al. 2017. Patients with chronic obstructive pulmonary disease walk with altered step time and step width variability as compared with healthy control subjects. *Annals of the American Thoracic Society* 14(6), pp. 858–866. Available at: www.atsjournals.org [Accessed: 30 November 2020].

Yoo, W.J. et al. 2008. Out-toeing and in-toeing in patients with Perthes disease: role of the femoral hump. *Journal of pediatric orthopedics* 28(7), pp. 717–22. doi: 10.1097/BPO.0b013e318186c4be.

Zaghloul, A. 2018. Hip Joint: Embryology, Anatomy and Biomechanics. *Biomedical Journal of Scientific & Technical Research* 12(3), pp. 001–015. Available at: https://biomedres.us/fulltexts/BJSTR.MS.ID.002267.php [Accessed: 6 August 2021].

Appendices

Appendix i: Search strategy for systematic review

MEDLINE:

(gait OR walking OR locomotion OR ambulation OR mobility OR compensate* OR adapt* OR deviate* OR variation OR alter* OR change* OR temporospatial OR kinematic OR kinetic) AND (“ non-operative perthes” OR “non-surgical perthes” OR “necrosis” OR “hip pathology”) AND (kid OR girl OR boy OR adolescent OR paediatric OR child*)

CINAHL:

(gait OR walking OR locomotion OR ambulation OR mobility OR compensate* OR adapt* OR deviate* OR variation OR alter* OR change* OR temporospatial OR kinematic OR kinetic) AND (“ non-operative perthes” OR “non-surgical perthes” OR “necrosis” OR “hip pathology”) AND (kid OR girl OR boy OR adolescent OR paediatric OR child*)

Cochrane:

(gait OR walking OR locomotion OR ambulation OR mobility OR compensate* OR adapt* OR deviate* OR variation OR alter* OR change* OR temporospatial OR kinematic OR kinetic) AND (“ non-operative perthes” OR “non-surgical perthes” OR “necrosis” OR “hip pathology”) AND (kid OR girl OR boy OR adolescent OR paediatric OR child*)

Appendix ii: Modified Downs and Black checklist

Reporting	**Score**	
1) Is the hypothesis/aim/objective of the study clearly described?	Yes No	1 0
2) Are the main outcome variables to be measured clearly described in the Introduction or Methods section? If the main outcomes are first mentioned in the Results section, the question should be answered “No”.	Yes No	1 0
3) Are the characteristics of the patients included in the study clearly described? For patients: Inclusion and/or exclusion criteria or case definition as well as a description of pathology/problem. Controls: Short characteristics description, e.g. “healthy normal controls without previous injuries”.	Yes No	1 0
4) Are the distributions of principal confounders in each group of subjects to be compared clearly described? A list of principal confounders is provided. Principal confounders include age, sex, height and weight.	Yes Partially No	2 1 0
5) Are measurement devices and data analysis procedures clearly stated? The type of device and resolution as well as the placement of the markers (model or exact placement) should be described.	Yes Partially No	2 1 0
6) Are the main findings of the study clearly described? Simple outcome data (including denominators and numerators) should be reported for all major findings so that the reader can check the major analyses and conclusions. (This question does not cover statistical tests, which are considered below.)	Yes No	1 0
7) Does the study provide estimates of the random variability in the data for the main outcomes? In non-normally distributed data, the inter-quartile range of results should be reported. In normally distributed data the standard error, standard deviation or confidence intervals should be reported. If the distribution of the data is not described, it must be assumed that the estimates used were appropriate and the question should be answered “Yes”.	Yes No	1 0
8) Have actual probability values been reported (e.g. 0.035 rather than < 0.05) for the main outcomes, except where the probability value is less than 0.001?	Yes No	1 0
External validity		
9) Were the subjects asked to participate in the study representative of the entire population from which they were recruited? The study must identify the source population for patients and describe how the patients were selected. Patients would be representative if they comprised the entire source population, an unselected sample of consecutive patients or a random sample. Random sampling is only feasible where a list of all members of the relevant population exists. Where a study does not report the proportion of the source population from which the patients are derived, the question should be answered “Unable to determine”.	Yes No Unable to determine	1 0 U
10) Were those subjects who were prepared to participate representative of the entire population from which they were recruited? The proportion of those asked who agreed should be stated. Validation that the sample was representative would include demonstrating that the distribution of the main confounding factors was the same in the study sample and the source population.	Yes No Unable to determine	1 0 U
11) Were the staff, places and facilities optimal for the measurements? If the measurements took place in a laboratory, it can be assumed that the staff of the laboratory did the measurements, and the question should be answered “Yes”.	Yes No Unable to determine	1 0 U
Internal validity – bias		
12) If any of the results of the study were based on “data dredging”, was this made clear? Any analyses that had not been planned at the outset of the study should be clearly indicated. If no retrospective unplanned subgroup analyses were reported, then answer “Yes”.	Yes No Unable to determine	1 0 U

13) Were the statistical tests used to assess the main outcomes appropriate? The statistical techniques used must be appropriate to the data. For example, non-parametric methods should be used for small sample sizes. Where little statistical analysis has been undertaken but where there is no evidence of bias, the question should be answered “Yes”. If the distribution of the data (normal or not) is not described, it must be assumed that the estimates used were appropriate and the question should be answered “Yes”.	Yes No Unable to determine	1 0 U
14) Were the main outcome measures used accurate (valid and reliable)? For studies where the outcome measures are clearly described, the question should be answered “Yes”. For studies that refer to other work or that demonstrate that the outcome measures are accurate, the question should be answered “Yes”.	Yes No Unable to determine	1 0 U
Internal validity – confounding (selection bias)		
15) Was there adequate adjustment for confounding in the analyses from which the main findings were drawn? If the effect of the main confounders was not investigated or confounding was demonstrated but no adjustment was made (e.g. kinetic values normalised to body weight or height etc.) in the final analyses, the question should be answered “No”.	Yes No Unable to determine	1 0 U
16) Were losses of patients to data contamination taken into account? If the numbers of patients lost to data contamination are not reported, the question should be answered “Unable to determine”. If the proportion lost to data contamination was too small to affect the main findings, the question should be answered “Yes”.	Yes No Unable to determine	1 0 U
Power		
17) Did the study have sufficient power to detect a clinically important effect where the probability value for a difference being due to chance is less than 5%?	No power analysis done or power < 70% Power 70%–80% Power > 80%	0 1 2
Total available score		20

Appendix iii: Participant Information Sheet for Parents and Carers of Patients with Perthes

[redacted]

Abdulrhman Mashabi PhD student
Cardiff University
[redacted]
Tel: [redacted]
Email: [redacted]

PhD Study: **Evaluation of Physical Functional Strategies, and Managing physiotherapy treatment for Non-Operative Children with Legg-Calve-Perthes Disease**

Who is the researcher?

My name is Abdulrhman Mashabi; I am a senior physiotherapist. I am carrying out PhD research and the topic I want to explore is about how perthes disease could affect daily activities such as: walking among children. In addition, I want to explore how patients with Perthes and their families manage the physiotherapy treatment that have been given in their daily lives.

Invitation:

I would like to invite you and your child to take part in our research study. Joining the study is entirely up to you, before you decide we would like you to understand why the research is being done and what it would involve for you and for your child. I will go through this information sheet with you at the same day of the research study or before coming on the trial day via email or phone, to help you decide whether or not you and your child would like to take part and answer any questions you may have. I suggest that you take as long as you need to read through the information sheet. Please feel free to talk to others about the study if you wish.

The first part of the Participant Information Sheet explains the purpose of the study and what will happen to you if you take part. Then more detailed information about the conduct of the study is provided.

Do ask if anything is unclear.

Why am I doing this research?

Children with legg calve perthes disease suffer from pain mainly during functional activities such as walking. After diagnosis of perthes disease, some instruction may have been given to patients with Perthes to reduce some physical activities that may affect their hip joint such as running and jumping activity. These restrictions in their lives may prevent them from enjoying in their leisure time activities and participating in activities with their peer group. Therefore, we need to understand how children with Perthes move during daily activities in order to decrease pain level and enhance their participation in leisure activities. We need to understand how patients with Perthes and their families mange physiotherapy treatment in their lives because there is a strong link between high adherence to physiotherapy management and the strong belief that physiotherapy is of value to patients with Perthes.

What will I have to do?

Firstly, you and your child will be asked to complete a questionnaire about daily activity such as walking and balance and manging physiotherapy treatment to enhance adherence to physiotherapy treatment. Secondly, your child will be asked to change into appropriate tight clothing (for example, shorts to the knee, well-fitting vest, swimming costume) so that we can attach a reflective marker (See the figure 1) to provide an accurate data. This process will be conducted with the upmost professionalism and a private area is provided for changing. During laboratory sessions, access to the laboratory is closed and a sign is placed on the door advising other staff not to enter whilst the trial is in progress. Then, retro-reflective markers (very light polystyrene or cork round markers) will be placed on your child's body. After your child becomes familiar with walking in the lab, your child will be asked to walk, balance and to stand up from a sitting position. For walking, your child will walk barefoot at self-selected speed along a 15 m walkway. For balance, your child will be asked to perform two kinds of balance activates. The first balance trial is standing with both legs on the floor while the second is standing on one leg Each activity will be performed 3 times for 30 seconds, and your child will have 5 seconds to maintain their posture before data collection. For sit to stand, your child will stand comfortably, and then asked to seat in small bench and return back to the original standing position repeated three times. When your child has completed all the activities, the reflective markers will be taken off from the child's body.

What is the device/procedure being tested?

This study is based on the VICON system, which consists of 8 camera and hidden force platform based on floor to record walking, balance and sit to stand data.

How can I get involved in the Perthes study?

Please contact me to express an interest in being included in this research study by [redacted]

How long will participation in the Perthes study take?

Your child's participation in this study will require one visit in the Research Centre for Clinical Kinaesiology (RCCK) in Cardiff University, [redacted]. On arrival, a copy of the information sheet and consent form will be provided. I will explain the full study to you and your child and ask for your consent, bearing in mind that you and your child are free to withdraw at any time. If your child is still interested in participating, you will sign the consent form and your child will sign the consent form. Then you and your child will be asked to complete three questionnaires regarding to physical activity and manging physiotherapy treatment. This visit will last for approximately 2 hours.

What are the possible side effects of taking part?

There will be no side effects that we are aware of; however, the performance of three activities may lead to fatigue. To minimize this effect, your child will be given a rest after each trial.

Is there any payment for taking part in this research?

Your child will receive a £20 gift voucher at the completion of the study.

What will happen to the information we collect?

Ethical and legal practice will be followed with respect to any information about you that is obtained during the study in accordance with the Data Protection Act. All information that is collected about you and your child during the course of this research will be kept strictly confidential. Any information that leaves the Cardiff University will have your name and address removed so that you cannot be recognised from it when you and your child consent to participation in this study. We may, with your consent, like to use photographs or video records for supporting this research. There is a section on the consent form for you and your child to give permission for this or not, and if permission is given, the images will be anonymised before use. If you are happy for images to be used anonymously, we will cover the face with a black square so that your child will not be recognised.

What if I am worried about any aspect of the research?

If you have a concern about any aspect of this study, you should speak to me and I will do my best to answer your questions. If you remain unhappy and wish to complain formally, you can do this by contacting the School of Healthcare Sciences Director of Research Governance [redacted] In the event that something does go wrong, and you are harmed during the research and this is due to someone's negligence then you may have grounds for a legal action for compensation against Cardiff University, but you may have to pay your legal costs.

What will happen if I don't want to carry on with the study?

You are free to leave the study at any time without giving a reason. If you do withdraw from the study, we will destroy all your identifiable data (name and contact details), but we will need to use the data collected up to your withdrawal.

What will happen to the results of the study?

The results of the study will be anonymised and possibly published in scientific journals and research conferences. If you would like a summary of the findings, I can send that to you at the end of the study.

Who is organising this study?

This study is being undertaken as part of my PhD at the Cardiff University, School of Healthcare Sciences.

Who has reviewed this study?

All research carried out on people is looked at by an independent group of people, called a Research Ethics Committee, to protect your interests. This study has been reviewed and given favourable opinion by Cardiff University School of Healthcare Sciences Research Ethics Committee.

Safeguarding of children and vulnerable adults

If I become aware of any information that suggests that you or another person might be at risk of harm, the local authority safeguarding children and vulnerable adult's procedures will be discussed with my supervisors and followed if required. This is keeping with Cardiff University's policies.

Who do I contact for further information?

If you have any further questions about the investigation, please do not hesitate to contact any of the following people:

[redacted]

Thank you for reading this information sheet.

V 1.0 – 20/06/2018

Appendix iv: Participant Information Sheet for Parents and Carers of Healthy Subject

[redacted]

Abdulrhman Mashabi PhD student
Cardiff University
[redacted]

PhD Study: **Evaluation of Physical Functional Strategies, and Managing physiotherapy treatment for Non-Operative Children with Legg-Calve-Perthes Disease**

Who is the researcher?

My name is Abdulrhman Mashabi; I am a senior physiotherapist. I am carrying out PhD research at Cardiff University and the topic I want to explore is about how perthes disease could affect functional activities such as walking among children. To understand how perthes patient move, your healthy child's data is important to provide comparable movement data to children with Perthes result.

Invitation:

I would like to invite you to take part in our research study. Joining the study is entirely up to you, before you decide we would like you to understand why the research is being done and what it would involve for you and for your child. I will go through this information sheet with you, to help you decide whether or not you and your child would like to take part and answer any questions you may have. I suggest that you take as long as you need to read through the information sheet. Please feel free to talk to others about the study if you wish. The first part of the Participant Information Sheet tells you the purpose of the study and what will happen to you if you take part. Then I will give you more detailed information about the conduct of the study.

Do ask if anything is unclear.

Why am I doing this research?

Children with legg calve perthes disease (LCPD) suffer from pain mainly during activities such as walking. After diagnosis of perthes disease, advice is often given to patients with Perthes to reduce some physical activities that may affect their hip joint such as running and jumping activity. These restrictions in their lives may prevent them from enjoying in their leisure time activities and to participate with their peer group. Therefore, we need to understand how they move during walking, balance and sit to stand in order to decrease pain and enhance their participation in leisure activities. To understand the perthes patient's movement, your child's data will be used as a comparable data So that we can understand how children without the disease move and perform certain activities.

What will I have to do?

Firstly, you and your child will be asked to complete two questionnaires about physical activity level and quality of life. Secondly, your child will be asked to change into appropriate tight clothing (for example, shorts to the knee, well-fitting vest, swimming costume) so that

we can attach a reflective marker (See the figure 1) to provide an accurate data. This process will be conducted with the upmost professionalism and a private area is provided for changing. During laboratory sessions, access to the laboratory is closed and a sign is placed on the door advising other staff not to enter whilst the study is in progress. Then, retro-reflective markers (very light polystyrene or cork round markers) will be placed on your child's body. After your child becomes familiar with walking in the lab, your child will be asked to walk, balance and to stand up from a sitting position. For walking, your child will walk barefoot at self-selected speed along a 15 m walkway. For balance, your child will be asked to perform two kinds of balance activates. The first balance trial is standing with both legs on the floor while the second is standing on one leg Each activity will be performed 3 times for 30 seconds, and your child will have 5 seconds to maintain their posture before data collection. For sit to stand, your child will stand comfortably, and then asked to seat in small bench and return back to the original standing position repeated three times. When your child has completed all the activities, the reflective markers will be taken off from the child's body.

What is the device/procedure being tested?

This study is based on the VICON system, which consists of 10 camera and hidden force platform based on floor to record walking, balance and sit to stand data.

How can I get involved in the Perthes study?

Contact me to express an interest in being included in this research study by [redacted]

How long will participation in the Perthes study take?

Your child participation in this study will require two visits to the Research Centre for Clinical Kinaesiology (RCCK) [redacted] The reason attending two sessions is to evaluate the consistency of the researcher when placing the marker on your children in order to get an accurate result. Your child will do same procedure in two sessions. On arrival, a copy of the information sheet and consent and assent form will be provided. I will explain the full study to you and your child and ask for your consent, bearing in mind that you and your child are free to withdraw at any time. If your child is still interested in participating, you will sign the consent form and your child will sign the assent form. Then you and your child will be asked to complete two questionnaires regarding to physical activity. Each visit will last for approximately 2 hours.

What are the possible side effects of taking part?

There will be no side effects that we are aware of; however, the performance of three activities may lead to fatigue. To minimize this effect, your child will be given a rest after each trial.

Is there any payment for taking part in this research?

Your child will receive a £20 gift voucher at the completion of the study.

What will happen to the information we collect?

Ethical and legal practice will be followed with respect to any information about you that is obtained during the study in accordance with the Data Protection Act. All information that is collected about you and your child during the course of this research will be kept strictly confidential. Any information that leaves the Cardiff University will have your name and address removed so that you cannot be recognised from it when you and your child consent to participation in this study. We may, with your consent, like to use photographs or video records for supporting this research. There is a section on the consent form for you and your child to give permission for this or not, and if permission is given, whether you and your child wish the images to be anonymised before use. If you are happy for images to be used anonymously, we will cover the face with a black square so that you will not be recognised.

What if I am worried about any aspect of the research?

If you have a concern about any aspect of this study, you should speak to me and I will do my best to answer your questions. If you remain unhappy and wish to complain formally, you can do this by contacting the School of Healthcare Sciences Director of Research Governance [redacted]. In the event that something does go wrong, and you are harmed during the research and this is due to someone's negligence then you may have grounds for a legal action for compensation against Cardiff University, but you may have to pay your legal costs.

What will happen if I don't want to carry on with the study?

You are free to leave the study at any time without giving a reason. If you do withdraw from the study, we will destroy all your identifiable data (name and contact details), but we will need to use the data collected up to your withdrawal.

What will happen to the results of the study?

The results of the study will be anonymised and possibly published in scientific journals and research conferences. If you would like a summary of the findings, I can send that to you at the end of the study.

Who is organising this study?

This study is being undertaken as part of my PhD at the Cardiff University, School of Healthcare Sciences.

Who has reviewed this study?

All research carried out on people is looked at by an independent group of people, called a Research Ethics Committee, to protect your interests. This study has been reviewed and given favourable opinion by Cardiff University School of Healthcare Sciences Research Ethics Committee.

Safeguarding of children and vulnerable adults

If I become aware of any information that suggests that you or another person might be at risk of harm, the local authority safeguarding children and vulnerable adult's procedures will be discussed with my supervisors and followed if required. This is keeping with Cardiff University's policies.

Who do I contact for further information?

If you have any further questions about the investigation, please do not hesitate to contact any of the following people:

[redacted]

Thank you for reading this information sheet.

V 1.0 – 20/06/2018

CARDIFF
UNIVERSITY
PRIFYSGOL
CAERDYDD

[redacted]

Appendix v: ***Information Sheet for Healthy Children***

Who am I?

My name is Abdulrhman Mashabi. I am Physiotherapist and I am doing a PhD research on children who suffer from pain in their thigh because of Perthes disease.

What is the Perthes Disease Project about?

I would like to know how children who suffer from pain in their thigh move during daily activities such as walking, balancing, standing and sitting activities to decrease pain and improve movements. To understand how these children patient's move, I will compare your movement during walking, balancing, standing and sitting activities to children patient's data to see the differences during functional activities. I will give you questionnaire that ask you about your physical activity. If this is difficult for you, another person can also help you to express yourself or speak on your behalf. Then you will do walking, balancing, standing and sitting activities in the lab. These activities will be recorded by digital Camera.

Why am I doing this?

Your movement data is important to compare it with children patient's data to decrease their pain and improve their movements.

What is involved?

I would like you to attend to the Research Centre for Clinical Kinaesiology (RCCK) in Cardiff University. You will complete questionnaire and doing walking, balancing, standing and sitting activities in two visits. The visit will last for approximately 2 hours. I would like you to attend in the Research Centre for Clinical Kinaesiology (RCCK) in Cardiff University. You will complete questionnaires and the do some activities in the lab such as walking, balancing, standing and sitting activities in one visit. This visit will last for approximately 2 hours. You will wear swimsuit to fix the markers (Figure 1) on your body in order to record your movement by especial camera (Figure 2). Using marker and special camera will provide me very useful information about your movement as you can see in figure 3.

(Figure 1) Reflective marker

(Figure 2) especial camera(.

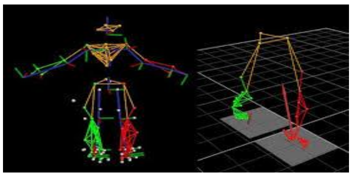


Figure 3) Your movement

What will this research be used for?

The information you give me will be used to compare your data to children patient's data to see the differences during functional activities.

V 1.0 – 20/06/2018

[redacted]

Appendix vi: Information Sheet for Children with Perthes Disease

Who am I?

My name is Abdulrhman Mashabi. I am Physiotherapist and I am doing a PhD research on children who suffer from pain in their thigh because of Perthes disease.

What is the Perthes Disease Project about?

I would like to know how children with Perthes disease move during daily activities such as walking, balancing, standing and sitting to decrease pain and improve movements. Also, I would like to know how patients and parents deal with medical advice because there is strong link between following medical advice and being able to move without pain. I will give you questionnaire that asks you about your physical activity and dealing with medical advice. If this is difficult for you, another person can also help you to express yourself or speak on your behalf. Then you will do walking, balancing, standing and sitting activities in the lab. These activities will be recorded by digital Camera to help me analysis your movement.

Why am I doing this?

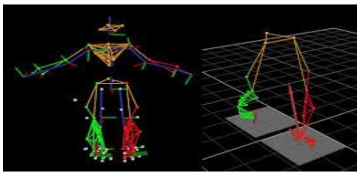
Perthes disease patients often suffer from pain that may make them reduce daily activities such as walking, balancing, standing and sitting. I am aiming to understand how can Perthes disease affect your movements during walking, balancing, standing and sitting activities. Also, I am aiming to express your views about medical advice and participating in daily activities with your friends to inform doctors about your condition.

What is involved?

I would like you to attend in the Research Centre for Clinical Kinaesiology (RCCK) in Cardiff University. You will complete questionnaires and the do some activities in the lab such as walking, balancing, standing and sitting activities in one visit. This visit will last for approximately 2 hours. You will wear swimsuit to fix the markers (Figure 1) on your body in order to record your movement by especial camera (Figure 2). Using marker and special camera will provide me very useful information about your movement as you can see in figure 3.

(Figure 1) Reflective marker

(Figure 2) especial camera.



(Figure 3) Your movement

What will this research be used for?

The information you give me will be used for talks and documents to inform people who treat Perthes disease patients how these patients move during daily activities and how they deal with medical advice to enhance treatment goal.

V 1.0 – 20/06/2018

Appendix vii

Consent Form for parents

Study Title: Evaluation of Physical Functional Strategies, and Managing physiotherapy treatment for Non-Operative Children with Legg-Calve-Perthes Disease

Please Initial box

1- I confirm that I have read the information sheet dated .... for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

2- I understand that my child and I participation are voluntary and that my child and I are free to withdraw at any time without giving any reason, without my legal rights being affected. ☐

3- I agree to photographs and video recordings being taken but my child's participation will remain confidential, and they will not be recognizable. ☐

4- I understand that all data recorded including photographs and videos will be stored securely for a minimum of 10 years following the end of the study. ☐

5- I do agree/do not agree (delete as applicable) for you to share anonymised information with external collaborators. ☐

6- I understand that the information collected about my child will be used to support this research and may be presented at conference and in scientific journals. ☐

7- <u>I agree to let my child take part in the above study</u> ☐

Name of child's parents	Date	Signature
Name of Person taking consent	Date	Signature

V 1.0 – 20/06/2018

Appendix viii

Assent form for children

Evaluation of Physical Activities, and Managing physiotherapy treatment for Children with Perthes Disease

Do I have to take part?

No, you can volunteer and change your mind at any time.

Safety and Well-being

Your safety is very important, if you tell me about something or someone in danger this will have to be reported to another adult in authority.

Your Consent

I have read the information leaflet (or had read to me) and understood the information given.

I have had time to think about the information and ask questions.

I know that this project will help Abdulrhman Mashabi learn more about Perthes disease.

I am happy to complete the questions and do the activities recording by camera without my face visible.

I understand that Abdulrhman may take photo and video for my movement, but the only used for this project and will not be identifiable.

I know that if I say something that suggests either myself or someone else is in danger then Abdulrhman will need to report this to a social worker or the police.

I know I can decide to stop the project at any time, and I don't have to say why. If this is the case, then I am happy for you to use any data recorded.

Your Name: ______________________________

Your Signature: ______________________________

Today's date: ______________________________

Parent/Guardian's Signature: __________________________

V 1.0 – 20/06/2018

Appendix ix

[redacted]

Abdulrhman Mashabi PhD student

Cardiff University

[redacted]

June 2018

Invitation to take part in a survey research study - **Evaluation of how Non-Operative Children with Legg-Calve-Perthes Disease mange the physiotherapy treatment.**

Dear Parent and Child

I would like to invite you and your child to take part in a research study that aims to identify how Patients with Perthes and family mange physiotherapy treatment to increase adherence to rehabilitation treatment. Before you decide whether or not to take part, you need to understand why this research is being done and what your involvement may consist of. I have therefore enclosed a Participant Information Sheet. This explains what the study is about, why you are being asked to participate, what participation would consist of, and how to find out more information.

Please feel free to contact me to ask questions if there is anything that you are unsure about. My details are at the top of this letter.

Thank you for taking the time to read this information.

With best wishes

Abdulrhman Mashabi

V 1.0 – 20/06/2018

Appendix x

General instruction:

1. There are no right and wrong answers — this is not a test.

2. Please answer all the questions as honestly and accurately as you can — this is very important.

V 1.0 – 20/06/2018

Appendix xi

Children's physical Activity Questionnaire (C-PAQ)

Child's Name:

Date of birth (dd/mm/yy):

Are you the child's: mother, father, guardian/ other.

Please note: -this questionnaire will take approximately 10 minutes to complete.

-please answer the questions in relation to the child above.

-please complete every line in the questionnaire.

Which of the following Physical Activities did your child do in **the PAST 7DAYS?**

Please complete this questionnaire for the following days:……………………...to…………………………..

Did you CHILD do the following activities in **the past 7 days?**		MONDAY- FRIDAY		SATURDAY-SUNDAY	
		How many times Mon-Fri?	Total Hours/minutes Mon-Fri?	How many times Sat-Sun?	Total Hours/minutes Sat-Sun?
EXAMPLE: Bike riding	NO [✓ YES]	2	40 mins	1	15 mins
Sport Activities Aerobics	No Yes				
Baseball/softball	No Yes				
Basketball/volleyball	No Yes				
Cricket	No Yes				
Dancing	No Yes				
Football	No Yes				
Gymnastics	No Yes				
Hockey (field or ice)	No Yes				
Martial Arts	No Yes				
Netball	No Yes				
Rugby	No Yes				
Running or jogging	No Yes				
Swimming lessons	No Yes				
Swimming for fun	No Yes				
Tennis/badminton/squash/ Other racquet sport	No Yes				
LEISURE TIME ACTIVITIES Bike riding (not school travel)	No Yes				
Bounce on the trampoline	No Yes				
Bowling	No Yes				
Household chores	No Yes				
Play in a play house	No Yes				

Play on playground equipment	No Yes				
Play with pets	No Yes				
Rollerblading/roller-skating	No Yes				
scooter	No Yes				

Did you CHILD do the following activities in **the past 7 days?**		MONDAY- FRIDAY		SATURDAY-SUNDAY	
		How many times Mon-Fri?	Total Hours/minutes Mon-Fri?	How many times Sat-Sun?	Total Hours/minutes Sat-Sun?
skateboarding	No Yes				
Skiing, snowboarding, sledging	No Yes				
Skipping rope	No Yes				
Tag	No Yes				
Walk the dog	No Yes				
Walk for exercise/hiking	No Yes				
ACTIVITIES AT SCHOOLS Physical education class	No Yes				
Travel by walking to school (to and from school= 2 times)	No Yes				
Travel by cycling to school (to and from school= 2 times)	No Yes				
Other Please state:	No Yes				

Did your Child do the following activities in **the past 7 days?**		**MONDAY-FRIDAY** **Total** hours/minutes	**SATURDAY-SUNDAY** **Total** hours/minutes
Example: Watching TV/videos	No [✓ Yes]		
Art and craft (e.g. Pottery, sewing, drawing, painting)	No Yes		
Doing homework	No Yes		
Imaginary play	No Yes		
Listen to music	No Yes		
Play indoor with toys	No Yes		
Playing board games/cards	No Yes		
Playing computer games e.g. PlayStation/Gameboy)	No Yes		
Playing musical instrument	No Yes		
Reading	No Yes		
Sitting talking	No Yes		

Talk on the phone	No Yes		
Travel by car/ bus to school (to and from school)	No Yes		[redacted]
Using computer/ internet	No Yes		
Watching TV/videos	No Yes		
Other (please state):	No Yes		

Appendix xii

KIDSCREEN Questionnaire					
About Your Health	Excellent	Very good	good	fair	poor
	😀	🙂	😐	🙁	☹
1. Have you felt fit and well?					
2. Have you felt full of energy?					
3. Have you felt sad?					
4. Have you felt lonely?					
5. Have you had enough time for yourself?					
6. Have you been able to do the things that you want to do in your free time?					
7. Have your parent(s) treated you fairly?					
8. Have you had fun with your friends?					
9. Have you got on well at school?					
10. Have you been able to pay attention?					
	Excellent	**Very good**	**good**	**fair**	**poor**
In general, how would you say your health is?					

Appendix xiii

A. ***Managing physiotherapy* treatment *Questionnaire : (For children)***

1. How do you usually go to school?

Car___.

Bus___.

Walking___.

Bicycle___.

Other: (could you write this down or draw it):

2. Which of the exercises causes pain in your hips? Please rank the degree of pain from 1 no pain to 7 most pain.

Walking ___.

setting with cross leg___.

stand on one leg____.

Runing___.

Jumping____.

Squating___.

walking up stair___.

Other: (could you write this down or draw it):

3. what do you usually do to relieve the pain?

Sleep or rest ___. Using cold/hot pack ___. Stretching ___. Taking medicine___.

Other: (could you write this down or draw it):

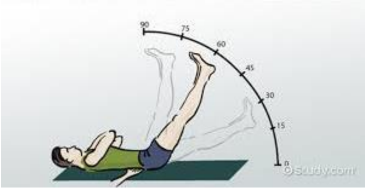
4. Have you been advised to avoid any of the following activities by a clinician or doctor? (you can choose more than one)

Cycling ___. Running___. Jumping___. Jumping on trampoline___.

Other: (could you write this down or draw it):

6. What kind of exercise(s) have you been advised to do at home? (You can tick more than one)

step up___.



Range of motion exercise___.

stand on one leg___.

Walking exercise___.

Stretching exercise___.

Muscle strength exercise___.

Other (could you write this down or draw it):

7. How frequently do you do home exercise?

Usually ___.

Sometimes____.

Rarely___.

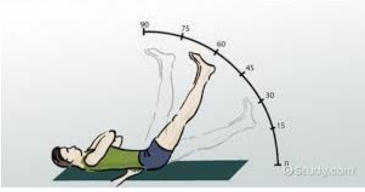
8. Do you have pain when you do the exercises at home?

☐ Yes

☐ No

9. Which of the following home exercises causes pain in your hips? Please rank the degree of pain from 1 no pain to 7 most pain.

step up___.



Range of motion exercise___.

stand on one leg___.

Walking exercise___.

Stretching exercise___.

Muscle strength exercise___.

Other: (could you write this down or draw it):

10. Which of the following are you concerned about it ? (put a number next to each picture 1 is more concerned, 4 is less concerned)

playing with your peers___. Participate in physical activity at school___. Pain___.

Playing at home____.

Other: (could you write this down or draw it):

Well Done

V 1.0 – 20/06/2018

B. *Managing physiotherapy* treatment *Questionnaire: (For parents)*

1. In which region do you live in?

☐ England
☐ Scotland
☐ Wales
☐ Northern Ireland

2. Which of your child's limbs is affected by Perthes

☐ Right
☐ Left
☐ Both

3. Do you have a positive family history of hip joint disease?

☐ Yes
☐ No

4. When was the first time your child was diagnosed with Perthes disease?

☐ Less 1 years
☐ 1-3 years
☐ 4-6 years
☐ 7-9 years
☐ More 10 years

5. What was the main manifestation that you noticed before your child was diagnosed with Perthes disease?

☐ Pain
    ☐ Lambing
    ☐ Imbalance
    ☐ Difficulty in walking
    ☐ Other:

6. Has your child had any operations?

☐ Yes
☐ No

7. What is your child Perthes disease stage?

☐ Mild stage
☐ Moderate stage
☐ Sever stage
☐ I am not sure

8. Has your child received physiotherapy?

☐ Yes
☐ No

9. How many times has your child attended the physiotherapy sessions per week?

☐ Once
☐ Twice
☐ Three times
☐ Other:

10. How long does each session last?

☐ 30 minutes
☐ 30-60 minutes
☐ More

11. What is the physiotherapist aim when he/she treats your child? (you can choose more than 1)

☐ Maintain daily activity level.
☐ Improve hip movement.
☐ Increase hip muscle strength.
☐ Decrease pain
☐ Improve balance
☐ Improve walking
☐ I do not know
☐ Other:

12. Which treatments has your child received during physiotherapy? (you can choose more than 1)

☐ Advice/education
☐ Heat therapy
☐ Cold therapy
☐ Stretches
☐ exercises
☐ Electrotherapy
☐ orthosis

☐ Other:

13. What is the level of motivation of your child during the treatment session?

☐ Low
☐ Medium
☐ High
☐ Other:

14. Did your child regularly do the exercises prescribed at home?

☐ Frequently
☐ Occasionally
☐ Rarely
☐ Never

15. What is your main concern about your child condition?

Thank you for completing the survey.

V 1.0 – 20/06/2018

Appendix xiv: Lab Risk assessment

Please Contact: [redacted]

Title of Investigation: Evaluation of Physical Functional Strategies, and Managing physiotherapy treatment for Non-Operative Children with Legg-Calve-Perthes Disease

Equipment	The VICON system that consists of Infrared Camera and force platform.
Description of the activity:	Gait Analysis including collection of static measures, video, and kinematic and kinetic data.
Person(s) undertaking activity:	[redacted]
Laboratory:	the Research Centre for Clinical Kinesiology

Risk	**Persons at Risk**	**Existing Control Measures**	**Severity** See Table 2	**Risk** See table 1	**Persons at Risk** SxL See table 3
Slips, and falls	Research Participants, visitors, and Staff	Acceptable lighting and a dry floor will be ensured prior to conducting any investigation.	2	1	2
Tripping over wires or cables on the floor of the gait laboratory	Research Participants, visitors, and Staff	Number of wires reduced to a minimum and those remaining are moved out of the way. Visitors will be warned of their presence when entering the laboratory.	2	1	2
Skin irritation due to the transpore tape or the double-sided tape used to attach retro-reflective markers.	Research Participants	Hypoallergenic tape used and research participants will be asked if they are allergic.	2	1	2
Risk of infection resulting contact with equipment/surfaces	Research Participants, visitors, and Staff	A cleaning regime has been put in place to clean all equipment before	1	2	2

		and after use. School cleaning crew to clean at least once per week.			

In addition to Cardiff University general risk assessment guidance, the Cardiff and Vale University Local Health Board RISK ASSESSMENT AND RISK REGISTER PROCEDURE (Version 1, published on 28th January 2011) was used to evaluate the scale of the risk. Tables below show the likelihood score and its description, the description of use of the risk matrix, and grading risk.

Likelihood score (L)

Likelihood score	**1**	**2**	**3**	**4**	**5**
Descriptor	**Rare**	**Unlikely**	**Possible**	**Likely**	**Almost certain**
Frequency How often might it /does it happen	This will probably never happen/recur	Do not expect it to happen/recur but it is possible it may do so	Might happen or recur occasionally	Will probably happen/recur but it is not a persisting issue	Will undoubtedly happen/recur. Possibly frequently.

🟩	1 - 3	Low risk
🟨	4 - 7	Moderate risk
🟧	8 - 12	High risk
🟥	15 - 25	Extreme risk

Risk Analysis Matrix – level of risk in terms of consequence (C) and likelihood (L), i.e. (C x L)

	Likelihood				
Likelihood score	**1**	**2**	**3**	**4**	**5**
	Rare	**Unlikely**	**Possible**	**Likely**	**Almost certain**
5 Catastrophic	5	10	15	20	25
4 Major	4	8	12	16	20
3 Moderate	3	6	9	12	15
2 Minor	2	4	6	8	10
1 Negligible	1	2	3	4	5

Grading Risk, the scores obtained from the risk matrix

OTHER ASSESSMENTS	
Are there any other assessments relating to this activity?	No
Has an electrical safety test been carried out?	Yes
Sources of Information and Codes of Practice (e.g. regulations, guidance notes...etc)	
1. *Vicon Nexus Manual 1.4 (Vicon Motion Systems Limited)*	
2. *Motek Medical D-Flow training syllabus*	
3. *the Cardiff and Vale University Local Health Board RISK ASSESSMENT AND RISK REGISTER PROCEDURE (Version 1, published on 28th January 2011)*	

DECLARATION

I have carried out all risk assessment to the best of my ability and training and in accordance with the procedure given in this University Guide Note

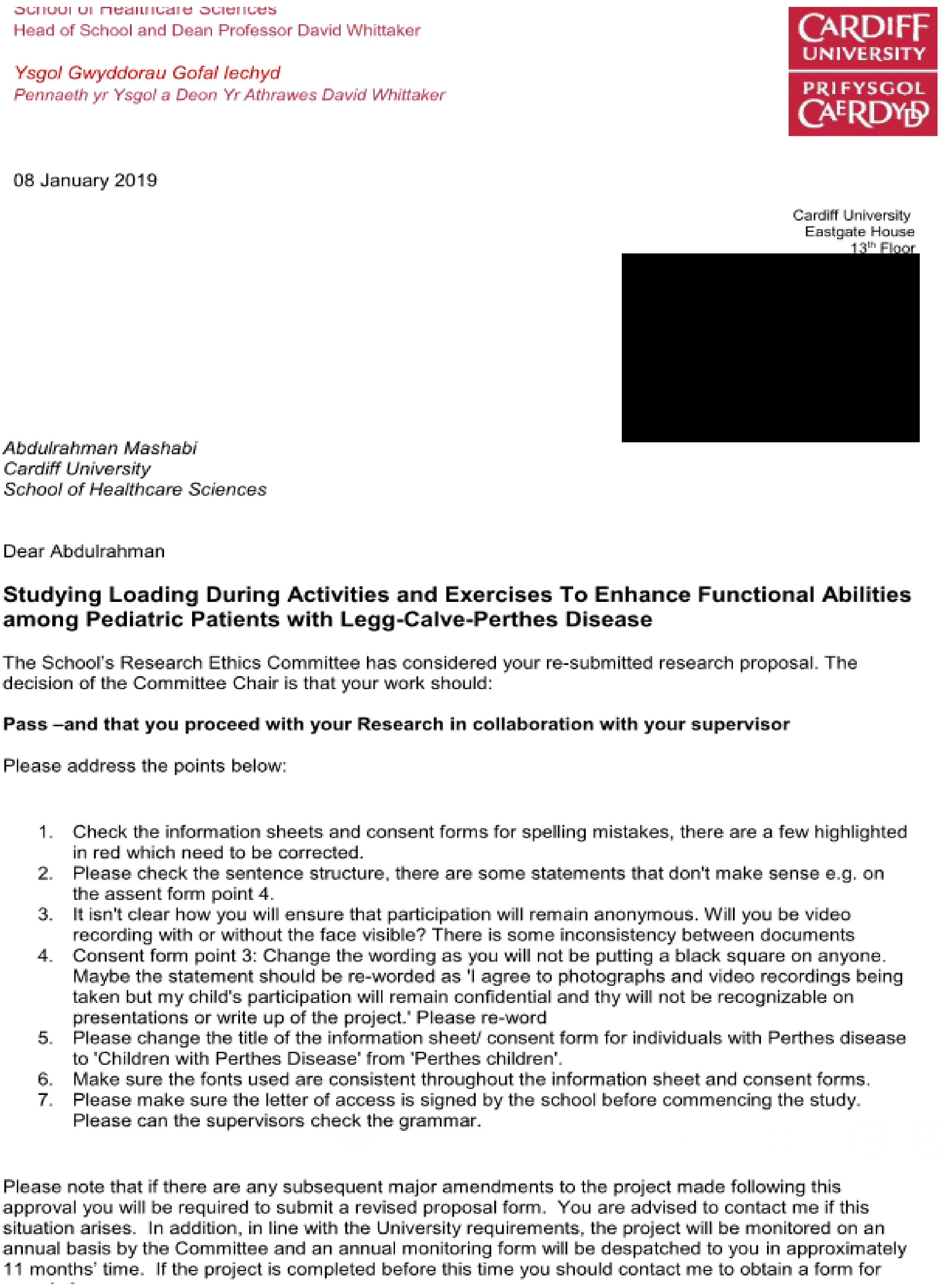
Name and signature of person completing the form:

Name: [redacted] Signature: [redacted] Date:**25/03/2018**

Name and signature of person agreeing to remedial measures and target dates:

Name: [redacted] Signature: [redacted] Date:**25/03/2018**

Appendix xv: Ethical Approval



School of Healthcare Sciences
Head of School and Dean Professor David Whittaker

Ysgol Gwyddorau Gofal Iechyd
Pennaeth yr Ysgol a Deon Yr Athrawes David Whittaker

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYD

08 January 2019

Cardiff University
Eastgate House
13th Floor
[redacted]

Abdulrahman Mashabi
Cardiff University
School of Healthcare Sciences

Dear Abdulrahman

Studying Loading During Activities and Exercises To Enhance Functional Abilities among Pediatric Patients with Legg-Calve-Perthes Disease

The School's Research Ethics Committee has considered your re-submitted research proposal. The decision of the Committee Chair is that your work should:

Pass –and that you proceed with your Research in collaboration with your supervisor

Please address the points below:

1. Check the information sheets and consent forms for spelling mistakes, there are a few highlighted in red which need to be corrected.
2. Please check the sentence structure, there are some statements that don't make sense e.g. on the assent form point 4.
3. It isn't clear how you will ensure that participation will remain anonymous. Will you be video recording with or without the face visible? There is some inconsistency between documents
4. Consent form point 3: Change the wording as you will not be putting a black square on anyone. Maybe the statement should be re-worded as 'I agree to photographs and video recordings being taken but my child's participation will remain confidential and thy will not be recognizable on presentations or write up of the project.' Please re-word
5. Please change the title of the information sheet/ consent form for individuals with Perthes disease to 'Children with Perthes Disease' from 'Perthes children'.
6. Make sure the fonts used are consistent throughout the information sheet and consent forms.
7. Please make sure the letter of access is signed by the school before commencing the study. Please can the supervisors check the grammar.

Please note that if there are any subsequent major amendments to the project made following this approval you will be required to submit a revised proposal form. You are advised to contact me if this situation arises. In addition, in line with the University requirements, the project will be monitored on an annual basis by the Committee and an annual monitoring form will be despatched to you in approximately 11 months' time. If the project is completed before this time you should contact me to obtain a form for

V 1.0 – 20/06/2018

Appendix xvi: Advertisement for Children with Perthes

CARDIFF
UNIVERSITY
PRIFYSGOL
CAERDYDD

UNDERSTANDING MOVEMENT OF CHILDREN WITH HIP PAIN

What

This is a PhD project aims to understand how per*thes patient could move.*

Who could participate?

> child age between 6-12 years
> diagnosed by unilateral perthes disease.
> without having surgery,

How?

your child will do walking, balancing and squating activities that recoding with digital camera *in the RCCK lab in Cardiff . University*. These data will help in understand how perthes patient could move.

£20 VOUCHER

Do you want to Participate in this project?

[redacted]

V 1.0 – 20/06/2018

Appendix xvii: Advertisement for typical development children

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

HEALTHY CHILDREN NEEDED TO HIP IN UNDERSTANDING MOVEMENT OF CHILDREN WITH HIP PAIN

What

This is a PhD project aims to understand how children with and without hip pain could move.

Who could participate?

> healthy child age between 6-12 years
> without any disease
> without having surgery.

How?

your child will do walking, balancing and squating activities that recoding with digital camera *in the RCCK lab in Cardiff . University*. These data will help in understand how children with and without hip pain could move

£20 VOUCHER

Do you want to Participate in this project?

[redacted]

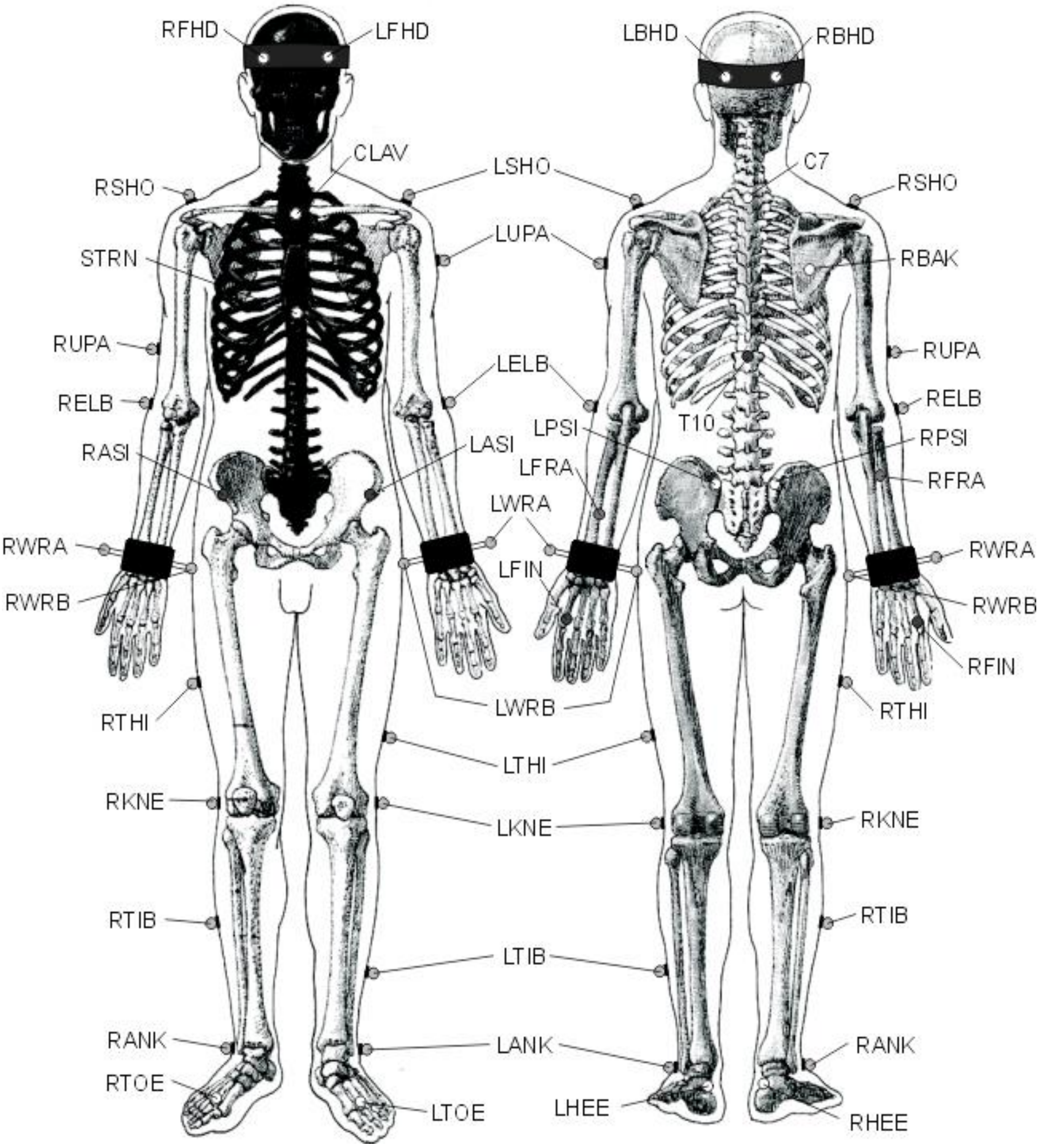
V 1.0 – 20/06/2018

Appendix xviii

Classification Instrument In Perthes (CLIPer)			
Domains of Assessment	Description	score	
Pain with ADLs	7 to 10/10	4	
	4 to 6/10	2	
	0 to 3/10	0	
Hip ROM	Less than 50% of uninvolved side for the majority of directions	6	
	50 to 75% of uninvolved side for the majority of directions	3	
	76 to 100% of uninvolved side for the majority of directions	0	
Balance	Paediatric balance score less than 50% of best score (best score=56) or less with eyes open less than 50% of time on uninvolved side.	6	
	Paediatric balance score less than 50 to 75% of best score (best score=56) or less with eyes open less than 50 to 75% of time on uninvolved side.	3	
	Paediatric balance score less than 76 to 100% of best score (best score=56) or less with eyes open less than 76 to 100% of time on uninvolved side.	0	
Gait	NWB and uses an assistive device and without AD, displays excessive gait deficits with decrease efficiency.	4	
	No assistive device and displays excessive deficits without a decrease in efficiency. Uses step to pattern on stairs	2	
	Non-painful limp Able to perform reciprocal pattern on stairs	0	
Total:			
Rehabilitation Classification Phase **Score total 14 to 24: Sever Involvement** **Score total 6 to 13: Moderate Involvement** **Score total 0 to 5: Mild Involvement**			

V 1.0 – 20/06/2018

Appendix xix



Plug-in-Gait Marker Placement

V 1.0 – 20/06/2018

Appendix xx: Healthy Subject data

1) Demographic Data

subject	gender	Dominant Side	age	Hight	weight	BMI	Pain (at start)	Pain (at walking)	Pain (at balance)	Pain (at squat)
1	Girl	Right	7	1.22	22.2	14.91	0	0	0	0
2	Boy	Right	10	1.38	38.8	20.37	0	0	0	0
3	Girl	Right	7.5	1.28	31.2	19.04	0	0	0	0
4	Boy	Left	9	1.26	24.2	15.24	0	0	0	0
5	Boy	Right	6	1.09	18	15.15	0	0	0	0
2	Girl	Right	7.5	1.2	22.4	15.55	0	0	0	0
7	Girl	Right	7	1.22	25.2	16.93	0	0	0	0
8	Girl	Right	6	1.09	18.6	15.65	0	0	0	0
9	Boy	Left	8	1.32	28	16.06	0	0	0	0
10	Boy	Right	11	1.4	32.2	16.42	0	0	0	0
11	Boy	Left	7	1.34	29	16.15	0	0	0	0
12	Girl	Right	7	1.2	19.8	13.75	0	0	0	0
13	Boy	Right	8	1.25	29.2	18.68	0	0	0	0
14	Girl	Right	12	1.44	31.6	15.23	0	0	0	0
15	Girl	Left	7	1.19	19	13.41	0	0	0	0

2) Passive Range of motion

Subject	Hip flexion		Hip extension		Hip adduction		Hip abduction		hip internal rotation		hip external rotation		knee flexion		knee extension		ankle Dorsiflexion		Ankle Plantarflexion	
	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.
1	130	135	25	25	20	28	45	45	25	30	35	38	110	115	3	0	25	20	45	45
2	130	130	25	20	25	24	44	38	43	45	55	45	120	120	2	2	23	23	55	53
3	120	110	20	15	25	20	41	41	46	35	52	45	110	115	3	3	30	25	45	45
4	115	120	15	13	22	27	42	42	42	45	45	45	132	105	4	3	28	40	53	55
5	130	135	15	15	30	25	43	42	36	40	39	45	125	130	5	4	25	20	45	48
6	150	135	20	15	22	22	40	38	35	35	40	42	140	125	3	5	45	40	65	60
7	130	130	20	20	28	23	35	35	45	40	55	50	135	140	2	3	28	25	65	55
8	130	120	12	12	26	22	38	40	30	35	38	32	135	140	1	2	30	33	41	47
9	122	125	10	5	22	25	45	39	40	42	45	36	138	140	3	5	35	40	50	50
10	120	140	10	12	18	20	42	35	26	50	40	30	145	140	4	2	33	25	48	55
11	135	132	15	10	19	23	36	43	30	35	43	35	139	140	5	3	30	30	45	47
12	125	130	10	10	26	25	44	38	35	55	45	35	148	140	2	2	20	22	47	50
13	145	135	10	10	20	25	40	39	45	50	52	45	145	155	4	4	45	35	57	60
14	125	105	16	20	20	22	39	40	39	40	42	35	150	162	1	3	40	25	40	47
15	135	135	18	15	20	27	40	43	42	40	40	40	150	150	5	5	30	42	51	60
Average	129.466	127.8	16.066	14.466	22.866	23.866	40.933	39.867	37.266	41.133	44.4	39.867	134.8	134.466	3.133	3.066	31.133	29.666	50.133	51.8

3) Muscle Strength Test:

Muscle strength test

Subject	Hip flexion		Hip extension.		Hip adduction		Hip abduction		Hip internal rotation		Hip external rotation		Knee flexion		Knee extension.		Ankle dorsiflexion		Ankle plantarflexion	
	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.
1	3.78	3.824	4.045	3.829	4.126	3.766	3.527	2.743	1.883	1.923	2.144	2.581	3.063	3.284	4.288	3.887	2.545	2.982	4.73	4.70
2	2.82	2.430	2.430	2.430	3.209	2.544	3.095	2.384	1.948	1.995	1.603	1.915	3.371	3.059	3.186	3.348	2.186	2.534	2.58	2.99
3	3.03	2.907	2.138	1.994	2.564	1.910	2.561	2.853	2.522	1.824	1.837	1.397	1.994	2.750	3.593	3.192	1.837	1.753	2.36	2.76
4	3.54	4.190	2.058	1.893	3.438	2.847	3.236	2.938	2.793	2.095	2.351	2.000	3.657	3.636	3.822	3.748	2.773	2.533	3.95	4.22
5	4.96	3.633	2.422	2.939	3.506	4.350	3.161	3.039	1.750	2.072	1.506	1.728	2.717	3.161	3.383	3.011	2.344	2.717	4.05	4.12
6	2.26	1.563	1.804	1.348	1.496	1.496	1.826	1.804	1.527	1.210	1.469	1.290	2.183	1.607	1.665	1.170	1.429	1.607	1.46	1.17
7	4.14	5.083	2.806	1.552	5.119	4.500	4.484	4.131	2.488	2.345	2.488	2.758	2.929	3.651	4.075	3.302	3.175	3.302	3.86	4.62
8	3.53	3.226	1.984	1.478	3.538	2.247	2.484	2.866	1.602	2.032	0.833	1.387	2.699	2.296	2.892	3.226	2.823	2.220	3.60	2.61
9	2.68	3.096	2.064	2.479	2.682	2.414	2.350	3.414	2.557	1.761	2.271	1.618	2.189	2.177	3.239	2.714	1.968	1.986	3.06	2.49
10	3.95	3.742	2.761	2.112	3.109	2.264	2.748	2.332	2.084	1.904	1.988	1.879	3.217	2.941	2.857	2.857	3.053	2.804	3.03	2.65
11	3.62	3.234	2.821	3.114	3.528	3.203	3.328	3.497	1.793	2.452	2.238	2.145	2.193	2.590	3.283	4.231	2.207	2.407	3.69	3.63
12	4.44	4.202	2.222	1.995	3.434	2.985	3.030	2.828	1.975	1.591	2.263	1.818	2.515	2.444	3.662	4.333	2.561	2.288	3.52	3.59
13	2.04	2.068	1.370	1.551	2.024	1.993	1.798	1.644	1.493	1.401	1.325	1.462	1.935	1.935	1.644	2.390	1.582	1.688	1.91	1.94
14	3.78	3.418	2.658	2.772	2.813	2.421	2.813	2.405	1.801	1.506	1.351	1.968	2.731	1.858	2.744	3.503	2.013	2.503	2.29	2.84
15	4.40	3.674	2.668	2.105	3.837	3.742	4.074	3.511	2.200	1.753	2.221	2.037	2.947	3.226	4.332	3.721	3.184	2.926	3.36	3.34
Average	3.53	3.353	2.417	2.239	3.228	2.845	2.968	2.826	2.028	1.858	1.859	1.866	2.689	2.708	3.244	3.242	2.378	2.417	3.16	3.18

4) Clinical examination

Subject	Leg length		Knee width		Ankle width		Trendelenburg sign		Thomas test	
	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.
1	0.711	0.711	0.191	0.191	0.132	0.132	No	No	No	No
2	0.762	0.762	0.226	0.226	0.140	0.140	No	No	No	No
3	0.686	0.686	0.213	0.216	0.132	0.132	No	No	No	No
4	0.686	0.686	0.183	0.183	0.127	0.124	No	No	No	No
5	0.584	0.584	0.165	0.160	0.097	0.097	No	No	No	No
6	0.673	0.673	0.185	0.185	0.127	0.124	No	No	No	No
7	0.686	0.686	0.206	0.206	0.135	0.130	No	No	No	No
8	0.599	0.599	0.157	0.157	0.122	0.122	No	No	No	No
9	0.711	0.711	0.198	0.198	0.147	0.147	No	No	No	No
10	0.800	0.800	0.201	0.201	0.152	0.152	No	No	No	No
11	0.737	0.737	0.203	0.203	0.147	0.147	No	No	No	No
12	0.660	0.660	0.160	0.160	0.122	0.122	No	No	No	No
13	0.686	0.686	0.191	0.191	0.127	0.127	No	No	No	No
14	0.787	0.787	0.203	0.203	0.140	0.140	No	No	No	No
15	0.635	0.635	0.152	0.152	0.114	0.114	No	No	No	No

Appendix xxi: Perthes Subject data

1) Demographic Data

subject	gender	Perthes Side	Dominant Side	age	hight	weight	BMI	Pain (at start)	Pain (at walking)	Pain (at balance)	Pain (at squat)
1	Boy	Rt.	Lt.	6	1.19	26.4	18.643	no	no	no	no
2	Boy	Lt.	Rt.	9	1.24	34.4	22.373	no	no	no	no
3	Girl	Lt.	Rt.	11	1.46	37.4	17.546	no	no	no	no
4	Boy	Rt.	Rt.	8	1.29	29.4	17.667	no	no	1	no
5	Girl	Lt.	Rt.	8	1.3	27.4	16.213	no	no	no	no
6	Girl	Rt.	Rt.	6	1.12	20.8	16.582	no	no	no	no
7	Boy	Rt.	Lt.	8	1.25	27.4	17.536	1	1	1	1
8	Boy	Rt.	Rt.	7	1.25	33.6	21.504	no	no	no	no
9	Boy	Rt.	Rt.	8	1.26	28.2	17.763	no	no	no	no

2) Passive ROM for Perthes:

Passive ROM for Perthes data																				
	Affected Perthes Leg										Non-affected Perthes leg									
	Hip						**Knee**		**Ankle**		**Hip**						**Knee**		**Ankle**	
Subject	Flex.	Ext.	Abd.	Add.	Internal	External.	Flex.	Ext.	Dorsi.	Plantar.	Flex.	Ext.	Abd.	Add.	Internal	External.	Flex.	Ext.	Dorsi.	Plantar.
1	120	10	20	38	32	45	150	3	30	50	120	10	20	39	47	49	140	0	25	48
2	122	10	12	44	30	33	142	0	23	48	105	15	18	39	39	35	140	0	40	50
3	128	20	24	43	40	40	138	5	30	45	128	16	22	40	40	40	140	4	30	55
4	115	11	20	40	23	42	150	5	25	40	145	10	25	47	45	32	145	5	23	40
5	130	10	23	45	45	35	65	3	45	60	140	10	20	47	45	54	65	5	35	60
6	122	10	15	45	22	42	150	5	25	35	135	12	20	35	30	30	140	3	25	45
7	142	14	22	44	42	38	152	4	45	55	155	15	23	46	42	40	152	5	30	55
8	125	15	22	39	28	32	150	5	30	45	132	13	24	43	35	38	148	6	40	50
9	145	15	23	43	31	47	145	4	25	50	133	13	22	52	26	40	150	2	30	45

3) Muscle strength test for Perthes:

Muscle strength test for Perthes data																				
	Affected Perthes Leg										Non-affected Perthes leg									
	Hip						**Knee**		**Ankle**		**Hip**						**Knee**		**Ankle**	
Subject	Flex.	Ext.	Abd.	Add.	Internal	External.	Flex.	Ext.	Dorsi.	Plantar.	Flex.	Ext.	Abd.	Add.	Internal	External.	Flex.	Ext.	Dorsi.	Plantar.
1	3.11	2.55	2.32	2.28	2.03	1.84	3.04	2.78	2.81	3.56	2.92	2.66	2.84	3.08	2.17	2.25	3.11	3.80	2.69	3.70
2	2.23	1.70	2.37	2.18	1.64	1.77	2.33	2.26	1.98	2.75	2.57	1.95	2.54	2.21	1.96	1.94	2.48	2.52	2.50	2.27
3	2.55	1.83	2.01	2.28	1.67	1.67	2.44	4.06	2.12	2.58	2.59	2.45	2.65	3.05	1.69	1.69	2.18	4.20	2.73	2.60
4	2.98	2.19	4.78	2.71	2.51	2.03	3.10	3.95	3.04	2.97	3.53	2.86	4.89	3.21	2.94	2.63	3.33	4.45	2.60	3.86
5	2.72	1.86	3.52	2.89	2.10	1.82	2.50	4.14	2.39	2.98	3.21	2.27	3.50	3.47	2.36	2.18	2.55	4.35	2.73	3.08
6	3.19	1.51	2.91	2.06	1.16	1.80	2.14	2.55	2.00	2.70	2.00	1.75	1.67	2.29	1.31	1.31	2.14	2.39	1.65	2.40
7	4.36	3.31	4.02	3.54	2.48	2.03	3.91	4.20	2.42	3.66	2.42	2.30	4.05	3.31	2.27	1.96	3.37	3.94	3.26	4.31
8	1.89	2.62	2.68	2.76	1.65	1.82	2.60	3.26	2.05	2.51	2.38	1.90	2.35	2.68	2.01	1.53	2.98	3.15	1.98	2.25
9	3.10	2.82	3.75	3.57	2.16	2.19	2.60	3.78	2.45	2.77	3.23	2.38	3.92	3.45	2.45	2.65	3.13	4.08	2.83	2.85

4) clinical examination

Subject	leg length		Single-leg Balance (Time s)		CLIPer Score	knee width		ankle width		Trendelenburg sign		Thomas test	
	Affected	nonaffected	Rt.	Lt.		Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.
1	0.658	0.660	10.9	25.3	3	0.203	0.203	0.127	0.127	no	yes	no	yes
2	0.673	0.648	10	8.5	7	0.254	0.244	0.135	0.127	no	no	no	no
3	0.584	0.594	11.45	6.08	3	0.198	0.206	0.145	0.145	no	no	no	yes
4	0.711	0.719	40	74	8	0.203	0.203	0.140	0.147	yes	no	no	no
5	0.737	0.747	74	40	5	0.191	0.191	0.135	0.140	no	no	no	yes
6	0.610	0.610	8.23	10.25	3	0.152	0.152	0.114	0.114	no	no	no	no
7	0.699	0.699	37	45	3	0.198	0.191	0.137	0.127	no	no	no	yes
8	0.699	0.704	12.12	12.85	0	0.226	0.213	0.147	0.147	no	no	no	no
9	0.686	0.686	16.58	23.83	5	0.198	0.198	0.137	0.137	no	no	yes	no
Average	0.673	0.674	24.476	27.312	4.11	0.203	0.200	0.135	0.135	-	-	-	-

Appendix xxii: Comparison between control and Perthes group data

1) Comparison between healthy and Perthes groups in Temporo-spatial walking parameters

	Comparison between healthy and Perthes groups in Temporo-spatial walking parameters																			
	Healthy Data								Perthes Data											
	Speed	Stride Width	Stride Length	Step Length	Step Time	Stance Time	Swing Time	Cadence	Speed	Stride Width	Stride Length	Step Length Affected	Step Length Non-affected	Step Time Affected	step time Nonaffected	Stance Time Affected	Stance Time Non-affected	Swing Time Affected	swing Time Non-affected	cadence
1	1.16	0.103	1.108	0.562	0.489	0.588	0.368	122.993	1.015	0.08	1.074	0.507	0.565	0.532	0.53	0.629	0.655	0.414	0.411	112.853
2	1.429	0.096	1.66	0.589	0.418	0.485	0.333	144.017	1.148	0.082	1.034	0.482	0.555	0.471	0.434	0.55	0.586	0.342	0.323	127.887
3	1.13	0.092	1.007	0.503	0.437	0.529	0.345	138.255	1.063	0.055	1.116	0.539	0.576	0.522	0.53	0.644	0.651	0.409	0.418	115.404
4	1.022	0.1	1.07	0.537	0.532	0.641	0.413	113.678	1.241	0.103	1.152	0.538	0.61	0.473	0.456	0.566	0.568	0.351	0.353	126.768
5	1.33	0.104	1.183	0.61	0.454	0.533	0.354	134.287	1.212	0.083	1.088	0.544	0.538	0.447	0.446	0.553	0.543	0.347	0.345	134.5
6	1.256	0.098	1.03	0.535	0.401	0.503	0.317	133.749	1.145	0.098	1.07	0.572	0.497	0.449	0.478	0.587	0.59	0.347	0.372	137.023
7	1.007	0.094	1.111	0.617	0.553	0.649	0.446	108.986	1.338	0.076	1.223	0.609	0.61	0.46	0.458	0.552	0.562	0.362	0.357	130.527
8	1.214	0.112	1.224	0.599	0.506	0.617	0.394	118.89	1.176	0.084	1.072	0.527	0.542	0.468	0.446	0.594	0.586	0.331	0.317	128.841
9	1.385	0.125	1.045	0.561	0.351	0.516	0.267	132.088	1.244	0.084	1.151	0.584	0.57	0.472	0.461	0.573	0.58	0.356	0.358	127.35
10	1.325	0.093	1.146	0.571	0.436	0.526	0.349	138.09												
11	1.088	0.094	1.102	0.547	0.496	0.609	0.404	121.312												
12	0.967	0.095	1.112	0.55	0.577	0.679	0.473	104.136												
13	1.162	0.05	1.083	0.537	0.456	0.572	0.362	120.735												
14	1.1	0.079	0.837	0.395	0.398	0.576	0.325	130.964												
15	1.149	0.091	0.972	0.555	0.477	0.606	0.368	121.862												

2) Comparison between healthy and Perthes groups in Kinematic parameters

Kinematic parameter of Walking for Healthy Subjects

Subject	Ankle fle/ext	Ankle abd/add	Ankle rotation	Hip fle/ext	Hip add/abd	Hip rotation	Knee fle/ext	Knee add/abd	Knee rotation	pelvic tilt	pelvic obliquity	pelvic rotation	Trunk tilt	Trunk obliquity	Trunk rotation
1	29.77	10.78	3.24	48.10	9.05	22.59	65.48	5.37	6.43	3.12	12.97	20.19	4.64	11.11	21.29
2	21.31	18.38	8.53	48.98	12.87	11.30	58.90	20.48	11.11	5.56	10.46	22.22	5.59	8.04	22.84
3	20.70	13.65	6.00	44.36	8.92	20.16	54.83	8.50	6.24	3.32	6.41	17.39	3.10	5.41	16.61
4	25.07	21.41	6.65	57.16	10.95	18.25	64.37	10.45	11.31	3.09	12.59	17.21	3.46	7.64	18.59
5	24.70	30.38	4.70	59.17	13.66	14.05	63.87	10.87	19.45	2.63	16.34	26.43	2.86	10.03	28.79
6	25.21	16.18	11.49	43.86	11.01	9.95	59.79	21.65	7.94	5.47	12.62	28.83	6.79	9.20	29.53
7	26.52	13.19	7.45	41.39	11.60	21.83	67.71	7.45	15.36	5.99	11.56	17.66	5.58	9.93	16.55
8	15.62	12.24	3.99	26.28	7.29	5.60	39.60	8.90	10.65	3.29	6.08	17.99	2.89	3.85	18.08
9	32.13	18.95	3.96	58.44	13.86	14.60	57.50	13.79	8.66	2.51	11.75	26.32	2.84	8.95	27.06
10	33.73	19.41	4.16	45.43	10.05	7.87	68.95	9.71	20.64	3.33	11.91	18.61	3.84	7.48	19.96
11	27.73	16.50	7.03	36.67	8.46	16.27	56.92	13.50	14.57	3.01	12.25	24.23	3.82	9.93	24.67
12	38.45	18.56	11.50	59.60	19.29	33.17	68.57	16.86	5.61	3.17	16.20	22.59	4.98	16.43	22.40
13	30.67	19.14	4.29	48.57	12.32	10.92	58.60	14.30	6.27	3.02	10.16	19.19	2.70	9.55	19.15
14	16.74	11.64	1.34	25.32	6.53	4.53	26.71	4.07	8.03	1.01	6.13	9.04	0.06	1.52	4.41
15	19.03	20.08	9.65	49.97	12.98	16.06	69.91	14.50	14.61	3.59	10.93	18.92	3.16	8.73	17.79

Kinematic parameter of Walking for Perthes Subjects

	Non-affected Perthes side												Affected Perthes Side														
	Pelvic tilt	Pelvic obliquity	Pelvic Rotation	Ankle Flex/ext	Ankle Add/abd	Ankle rotation	Hip Flex/ext	Hip Add/abd	Hip rotation	Knee Flex/ext	Knee add/abd	Knee rotation	Pelvic tilt	Pelvic obliquity	Pelvic Rotation	Ankle Flex/ext	Ankle Add/abd	Ankle rotation	Hip Flex/ext	Hip Add/abd	Hip rotation	Knee Flex/ext	Knee add/abd	Knee rotation	Trunk tilt	Trunk obliquity	Trunk rotation
1	4.21	8.90	33.06	40.95	34.96	14.32	48.10	9.99	26.63	60.58	26.75	19.08	3.62	10.25	13.80	33.77	20.81	5.66	34.57	7.32	8.77	52.18	17.11	13.62	3.98	5.82	15.08
2	5.51	17.74	20.98	25.54	20.14	13.15	57.85	14.91	4.54	62.41	6.87	7.82	2.19	10.03	17.67	21.05	20.68	11.84	40.36	11.10	21.58	19.20	41.40	8.97	5.70	10.47	22.42
3	5.23	6.50	10.38	34.68	20.84	9.88	38.45	9.24	15.23	55.62	11.26	14.83	2.92	6.83	6.97	38.14	37.18	16.64	43.20	11.08	50.05	38.53	37.91	10.51	4.90	5.80	10.32
4	6.53	3.44	22.78	29.83	41.80	8.08	51.15	8.62	45.31	65.29	13.69	21.08	4.74	8.65	15.82	31.19	26.53	3.80	36.17	3.55	10.65	62.06	8.87	13.42	5.15	7.84	16.18
5	3.20	8.15	18.19	31.07	19.26	5.92	45.73	13.18	8.56	67.45	5.45	8.67	6.19	4.86	24.01	31.17	20.37	7.27	32.04	6.12	18.04	53.79	9.49	13.44	3.06	4.63	18.67
6	9.95	17.50	26.11	37.98	20.52	9.85	69.28	19.74	29.65	51.08	25.91	8.81	4.12	14.00	13.76	26.34	33.25	10.39	51.50	8.63	11.06	69.74	13.14	12.56	4.34	8.69	15.74
7	3.13	3.34	14.84	33.77	32.76	4.49	53.70	10.32	23.47	66.87	16.10	8.61	3.34	23.50	25.35	30.09	30.92	3.70	50.49	8.56	14.26	63.08	29.88	11.45	4.63	21.67	26.35
8	3.41	5.22	18.25	25.32	40.20	7.71	52.01	11.11	35.56	67.90	23.30	13.78	4.59	8.40	17.16	23.01	36.09	8.96	47.96	6.40	9.69	67.52	27.25	29.92	4.70	7.72	17.62
9	6.12	11.84	26.25	37.42	33.43	5.75	50.63	16.42	10.06	75.84	18.27	23.22	6.06	16.30	16.73	24.65	26.48	7.16	45.12	16.67	9.06	64.14	8.32	14.21	6.79	9.05	20.37

3) Comparison between healthy and Perthes groups in Peak of Kinetic parameters

Kinetic parameter for Healthy Subjects								
Subject	Ankle extensor Moment	Ankle Power	Hip extensor Moment	Hip abductor Moment	Hip Power	Knee extensor Moment	Knee abduction Moment	Knee Power	V GRF
1	1.04	1.89	0.50	0.42	0.78	0.44	0.23	0.84	1.31
2	0.87	2.50	0.60	0.46	1.48	0.22	0.21	0.97	1.05
3	0.54	1.62	0.27	0.30	0.98	0.24	0.09	0.26	1.05
4	0.88	2.03	0.24	0.26	0.82	0.35	0.18	0.25	1.08
5	0.42	0.92	0.49	0.23	1.87	0.38	0.06	2.35	1.41
6	0.53	1.24	0.51	0.36	1.36	0.22	0.04	1.81	0.80
7	0.55	0.95	0.25	0.35	0.74	0.21	0.06	0.14	1.07
8	1.05	2.46	0.37	0.43	0.97	0.11	0.23	1.76	1.26
9	0.64	1.48	0.31	0.28	0.96	0.45	0.03	0.99	1.13
10	0.79	1.68	0.78	0.71	1.24	0.49	0.24	1.14	0.98
11	1.04	2.72	0.43	0.46	0.92	0.26	0.05	0.37	1.09
12	0.73	1.25	0.22	0.43	0.54	0.33	0.13	0.63	1.20
13	0.89	2.20	0.50	0.57	1.00	0.34	0.06	0.68	0.80
14	0.95	1.68	0.55	0.49	0.90	0.84	0.17	0.93	1.23
15	0.71	0.96	0.41	0.44	0.35	0.38	0.06	0.50	1.18

Kinetic parameter for Perthes Subjects																		
Subject	Affected Perthes Side									Non-affected Perthes Side								
	Ankle ext. Moment	Ankle Power	Hip ext. Moment	Hip abd. Moment	Hip Power	Knee ext. Moment	Knee abd. Moment	Knee Power	V GRF	Ankle ext. Moment	Ankle Power	Hip ext. Moment	Hip abd. Moment	Hip Power	Knee ext. Moment	Knee abd. Moment	Knee Power	V GRF
1	0.92	2.75	1.09	0.69	1.42	0.64	0.28	0.81	1.35	0.65	1.52	0.68	0.62	0.99	0.61	0.12	0.21	1.33
2	1.09	3.04	0.93	0.84	1.43	0.86	0.30	1.71	1.26	0.82	1.76	0.76	0.56	1.44	0.17	0.25	0.71	1.21
3	1.24	2.90	1.11	0.89	1.33	0.42	0.47	0.85	1.15	1.30	2.92	0.50	1.11	0.62	0.35	0.53	0.28	1.09
4	1.26	3.28	1.04	0.65	1.13	0.75	0.19	2.25	1.07	1.25	4.06	0.75	0.74	1.55	0.55	0.22	0.64	1.21
5	1.12	3.14	0.89	0.80	1.15	0.74	0.19	1.77	1.21	1.12	2.43	0.78	0.79	1.46	0.28	0.21	0.79	1.22
6	0.98	2.21	1.09	0.47	2.47	0.46	0.22	2.83	1.14	1.11	3.30	0.88	0.60	1.89	0.07	0.07	1.33	1.18
7	1.29	3.28	1.38	0.74	3.26	1.19	0.38	4.17	1.33	1.20	3.72	0.46	0.63	1.77	0.69	0.33	0.85	1.23
8	0.94	2.24	1.29	0.67	2.12	0.72	0.49	2.23	1.13	1.14	3.71	1.15	0.47	2.88	0.42	0.31	0.88	1.09
9	1.10	2.70	0.84	0.85	1.26	0.57	0.32	2.26	1.14	1.05	3.41	0.64	0.69	1.08	0.68	0.07	0.93	1.22

4) Comparison between healthy and Perthes groups in single-leg balance parameters

Single-leg balance parameters for Healthy Subjects

Subject	COP area	Peak of V GRF	Hip flex/ extension	Hip ad/ abduction	Hip rotation	Peak of hip extensor Moment	Peak of hip abductor Moment	Hip Power	Pelvic tilt	Pelvic ad/ abduction	Pelvic rotation	Trunk tilt	Trunk ad/ abduction	Trunk rotation
1	0.010	1.32	13.42	8.13	8.47	0.51	0.49	0.46	8.18	27.88	10.80	6.52	23.23	20.27
2	0.005	0.92	19.28	7.15	11.78	0.43	0.68	0.92	3.56	7.01	4.93	3.57	7.16	4.33
3	0.004	0.67	15.51	13.00	26.18	0.33	0.74	0.24	8.60	12.47	9.00	8.62	11.88	9.09
4	0.008	0.82	18.26	15.12	5.03	0.56	0.67	1.39	12.98	13.99	9.37	13.50	14.17	10.00
5	0.004	0.74	9.77	10.83	7.65	0.37	0.51	0.29	10.30	7.90	8.01	9.77	9.70	6.25
6	0.016	0.97	40.15	18.57	16.26	0.51	0.70	0.42	8.49	37.95	10.11	9.04	36.80	13.79
7	0.010	1.11	25.77	8.36	10.16	0.61	0.41	0.48	6.63	21.57	12.83	6.48	23.20	10.55
8	0.014	1.07	4.30	4.04	3.71	0.18	0.26	0.12	4.00	3.04	4.35	3.92	3.04	4.31
9	0.007	1.02	15.39	9.87	9.61	0.53	0.53	0.77	19.74	16.48	12.74	19.75	13.95	15.27
10	0.013	0.68	34.49	10.15	20.45	1.04	1.36	1.31	9.05	17.88	5.89	10.37	17.06	7.26
11	0.010	1.32	7.87	16.19	8.68	0.29	0.70	0.29	8.95	14.92	8.27	8.42	13.60	9.36
12	0.010	0.92	6.74	5.92	10.80	0.42	0.52	0.24	8.53	7.10	6.74	8.75	7.66	6.87
13	0.005	0.67	22.79	11.41	37.21	0.28	0.66	0.69	7.43	8.74	3.14	7.12	9.05	3.04
14	0.004	0.82	18.79	15.41	9.73	0.27	0.71	0.37	5.62	11.91	10.19	24.04	11.59	6.52
15	0.008	0.74	5.72	4.65	4.18	0.15	0.12	0.18	1.00	2.69	2.25	4.33	2.68	2.17

Single-leg balance parameters for Perthes Subjects

	Affected Perthes Side															Non-affected Perthes Side														
S	COP area	Peak of V GRF	Hip fle/ ext	Hip ad/ abd	Hip rotation	Peak of hip ext. Moment	Peak of hip abd Moment	Hip Power	Pelvic tilt	Pelvic add/ abd	Pelvic rotation	Trunk tilt	Trunk add/ abd	Trunk rotation	Area	Peak of V GRF	Hip fle/ext	Hip ad/abd	Hip rotation	Peak of hip ext. Moment	Peak of hip abd Moment	Hip Power	Pelvic tilt	Pelvic add/ abd	Pelvic rotation	Trunk tilt	Trunk add/ abd	Trunk rotation
1	0.010	0.96	5.08	7.54	6.00	0.15	0.25	0.11	2.99	5.05	4.64	3.15	4.16	5.30	0.010	0.94	3.98	3.03	5.65	0.18	0.22	0.14	3.99	6.16	4.64	4.26	5.16	4.30
2	0.017	1.22	7.04	4.10	9.99	0.28	0.15	0.09	3.65	4.19	7.57	4.37	5.47	2.48	0.006	1.21	2.21	8.31	3.22	0.32	0.13	0.11	4.65	5.30	9.57	6.45	4.47	3.48
3	0.016	1.28	2.33	2.00	8.78	0.12	0.16	0.11	3.13	1.68	4.27	1.64	2.79	1.51	0.030	1.24	3.40	5.25	6.13	0.22	0.13	0.16	5.13	2.62	5.27	2.64	3.79	2.51
4	0.011	1.02	4.82	6.00	6.14	0.17	0.27	0.21	2.60	7.67	13.52	2.63	9.59	11.54	0.027	0.90	4.49	12.23	17.48	0.20	0.21	0.14	5.60	7.67	18.56	2.63	859	13.54
5	0.020	0.96	20.21	14.94	12.07	0.54	0.82	0.72	13.19	13.00	28.50	3.65	20.11	9.39	0.034	0.94	7.92	3.83	2.86	0.58	0.40	0.26	6.19	6.53	30.6	4.65	17.11	8.39
6	0.012	0.94	3.74	11.29	6.05	0.26	0.29	0.11	7.92	3.83	2.86	7.78	3.87	3.01	0.009	0.75	19.51	19.90	49.09	0.26	0.25	0.42	9.92	3.83	2.86	9.78	2.87	4.01
7	0.005	1.15	6.50	5.37	3.91	0.32	0.24	0.22	3.20	9.45	6.66	3.48	9.69	4.83	0.005	1.10	19.91	13.73	38.54	0.38	0.22	0.33	8.20	10.63	6.66	5.47	8.69	5.83
8	0.012	0.98	6.86	7.43	5.23	0.21	0.33	0.18	5.13	4.52	8.90	5.15	4.16	9.33	0.010	1.18	12.92	8.55	11.40	0.25	0.31	0.35	6.13	6.52	9.70	6.19	6.16	8.33
9	0.012	0.96	6.70	7.45	6.1	0.33	0.36	0.25	5.30	4.9	7.0	4.15	5.3	6.2	0.013	0.96	6.3	7.6	8.3	0.38	0.34	0.34	7.30	7.45	9.01	5.15	6.3	7.3

5) Comparison between healthy and Perthes groups in Squat parameters

Squat activity data for Healthy Subjects

Subject	Ankle flex/extension	Hip flex/extension	Hip ad/abduction	Hip rotation	Peak of hip extensor moment	Peak of hip abductor. moment	Hip Power	Pelvic tilt	Pelvic obliquity	Pelvic rotation	Knee flex/extension	Trunk tilt	Trunk obliquity	Trunk rotation
1	41.580	76.804	16.371	39.181	-0.028	0.181	1.356	10.444	8.706	7.292	104.319	10.586	8.469	6.800
2	48.565	99.873	47.501	37.611	-0.027	0.839	1.831	23.494	8.356	11.211	140.510	23.819	9.991	9.188
3	46.264	84.794	35.815	19.256	0.054	0.772	0.642	14.304	5.900	4.963	118.573	14.337	5.540	4.874
4	42.255	128.754	21.003	31.674	0.154	0.611	3.272	34.213	17.865	14.005	132.373	35.674	15.893	15.938
5	61.802	91.451	28.451	14.109	-0.072	0.790	2.669	45.099	14.636	7.228	160.223	46.313	11.730	8.397
6	36.499	83.744	14.313	16.439	0.075	0.311	1.861	18.270	11.214	6.343	101.301	18.276	10.872	6.931
7	31.229	73.086	22.906	16.627	0.010	0.568	1.211	16.068	7.268	6.257	84.750	16.252	6.754	6.633
8	51.641	83.024	18.463	14.192	-0.008	0.746	1.760	26.724	12.339	6.068	124.857	26.773	12.444	6.746
9	40.062	80.735	34.963	25.057	0.011	0.581	2.261	25.234	9.407	9.382	106.213	25.363	8.439	11.514
10	49.196	76.985	10.711	29.995	0.015	0.419	1.111	22.667	6.348	4.930	112.168	22.709	6.847	4.940
11	38.076	74.860	19.634	11.129	-0.033	0.587	1.270	23.859	19.102	5.083	102.774	24.351	19.011	4.414
12	59.936	89.032	32.390	20.977	0.109	0.799	1.896	29.012	7.085	9.014	137.322	29.257	7.644	9.428
13	62.594	83.401	53.575	39.667	0.065	0.860	1.898	27.704	8.627	7.006	144.779	27.487	8.874	6.954
14	49.274	73.092	16.013	10.074	-0.130	0.457	1.019	24.726	5.525	4.545	106.976	24.740	5.926	4.011
15	25.119	74.441	16.903	16.161	0.004	0.366	1.099	19.026	10.219	7.686	74.051	19.135	10.663	7.717

Squat activity data for Perthes Subjects

subject		Ankle flex/extension	Hip flex/extension	Hip ad/abduction	Hip rotation	Peak of hip extensor moment	Peak of hip abductor. moment	Hip Power	Pelvic tilt	Pelvic obliquity	Pelvic rotation	Knee flex/extension	Trunk tilt	Trunk obliquity	Trunk rotation
1	Affected Perthes Side	82.639	44.297	11.317	14.652	0.532	0.378	1.801	25.695	6.658	6.698	13.529	25.917	6.511	14.826
2		46.778	72.448	23.954	39.510	0.885	0.706	1.702	26.794	14.803	7.884	94.516	26.720	14.781	9.601
3		52.336	50.270	10.643	19.075	0.840	0.311	3.770	25.695	6.658	6.698	79.286	26.720	14.781	9.601
4		36.214	75.285	11.305	7.346	1.046	0.270	2.639	24.451	15.988	8.748	106.555	25.182	12.714	11.218
5		37.627	26.852	10.472	22.172	0.409	0.303	0.645	9.819	8.701	7.530	65.733	9.825	9.623	7.527
6		40.792	114.578	31.285	40.176	1.173	0.921	4.052	8.387	15.129	5.227	126.842	8.200	14.956	5.913
7		36.122	94.650	15.626	20.901	1.352	0.335	4.429	38.659	15.774	8.536	87.572	39.558	16.226	10.694
8		31.903	81.928	25.830	32.588	1.034	0.663	2.810	36.187	15.157	7.964	98.686	35.840	15.998	11.140
9		31.903	81.928	25.830	32.588	1.034	0.663	2.810	36.187	15.157	7.964	98.686	35.840	15.998	11.140
1	Nonaffected Perthes Side	52.336	50.270	10.643	19.075	0.840	0.311	3.770	25.695	6.658	6.698	79.286			
2		41.996	74.705	21.208	12.869	1.210	0.705	1.947	26.794	14.803	7.884	92.831			
3		82.639	44.297	11.317	14.652	0.532	0.378	1.801	25.695	6.658	6.698	13.529			
4		37.127	70.710	9.305	7.161	0.579	0.218	1.547	24.451	15.988	8.748	95.312			
5		34.348	23.474	7.826	9.835	0.351	0.207	0.619	9.819	8.701	7.530	76.807			
6		46.551	107.390	26.432	31.401	0.908	0.648	2.778	8.387	15.129	5.227	127.618			
7		34.674	102.713	19.502	41.098	1.635	0.508	4.958	38.659	15.774	8.536	104.465			
8		32.083	93.176	32.433	34.344	1.811	0.813	6.497	36.187	15.157	7.964	106.124			
9		32.083	93.176	32.433	34.344	1.811	0.813	6.497	36.187	15.157	7.964	106.124			

6) Comparison between healthy and Perthes groups in Physical activity Questionnaire (C-PAQ)

Physical activity Questionnaire (C-PAQ) for Healthy and Perthes groups														
	Heathy Subject							Perthes subject						
Subject	Sports Activity		Leisure time activities		Activities at school	Activity at home		Sports Activity		Leisure time activities		Activities at school	Activity at home	
	weekdays	Weekend	Weekdays	weekend	Weekdays	Weekdays	weekend	weekdays	Weekend	Weekdays	weekend	Weekdays	Weekdays	weekend
1	390	120	135	120	115	2400	1140	30	75	225	105	0	1050	480
2	240	120	240	150	120	1560	960	120	0	210	0	0	300	300
3	180	60	240	120	120	1440	1200	0	0	60	0	0	250	250
4	130	0	0	80	80	250	360	45	45	0	30	0	336	420
5	110	0	70	0	0	1440	0	130	80	480	60	45	480	220
6	125	175	70	90	50	330	180	20	10	15	0	60	2760	1200
7	260	120	105	30	50	510	1140	105	18	0	0	50	360	720
8	100	120	45	30	50	510	1170	195	60	50	265	190	900	720
9	510	180	90	100	100	960	1260	525	165	885	60	40	1575	720
10	90	90	0	120	20	315	0							
11	370	70	190	45	0	3120	1860							
12	0	10	60	60	57	1440	1320							
13	20	20	60	20	10	830	606							
14	25	25	15	15	60	840	900							
15	60	60	20	30	30	500	750							

7) Comparison between healthy and Perthes groups in Quality of life (KIDSCREEN-10) Questionnaire

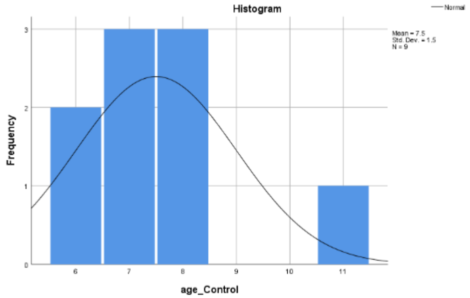
Quality of life (KIDSCREEN-10) Questionnaire for Healthy and Perthes groups																						
	Healthy subject											**Perthes subject**										
Subject	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11
1	5	5	5	5	5	5	5	5	5	5	5	5	5	2	3	5	3	3	5	4	5	4
2	5	5	5	5	5	1	5	5	5	5	5	4	5	2	4	3	2	5	4	3	3	3
3	5	5	5	5	5	5	5	5	5	5	5	3	3	3	3	4	3	5	5	3	5	4
4	4	5	3	4	4	5	5	5	5	5	4	4	4	3	5	5	2	4	5	5	5	4
5	5	5	5	3	5	5	5	5	5	5	5	4	4	2	3	1	4	4	3	3	5	3
6	5	4	1	1	4	4	4	4	4	4	5	3	4	3	3	3	4	4	4	4	4	4
7	4	4	3	3	4	2	5	4	4	4	3	5	5	1	1	5	3	5	5	5	5	4
8	3	5	5	5	5	5	5	5	5	3	5	4	4	3	4	4	4	4	4	4	4	5
9	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4	5	5	5	5	4
10	5	5	5	5	5	5	5	5	5	5	5											
11	5	5	1	1	5	5	5	5	5	5	5											
12	3	5	5	5	5	5	5	3	4	5	3											
13	3	5	3	5	5	4	5	5	5	5	5											
14	5	5	5	1	4	4	5	5	5	5	4											
15	5	5	5	5	5	5	5	5	5	5	5											

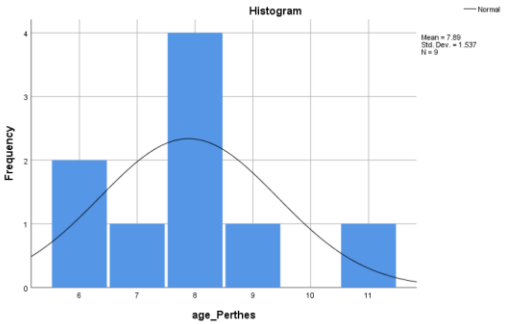
Appendix xxiii:Test of Normality

1) Demographic Data: A) Age

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
age_Control	.818	9	.033
age_Perthes	.896	9	.231

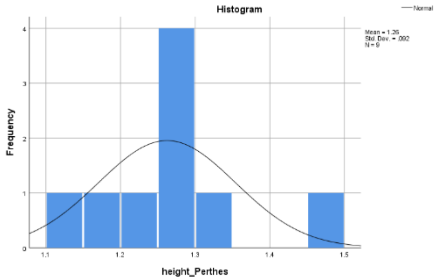


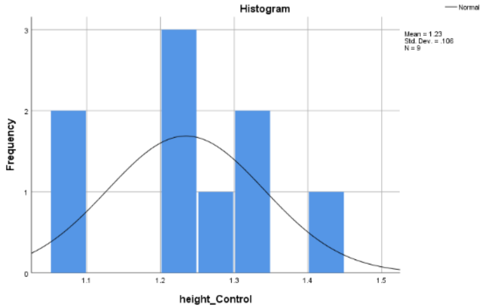


B) Height

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
height_Control	.944	9	.620
height_Perthes	.901	9	.256

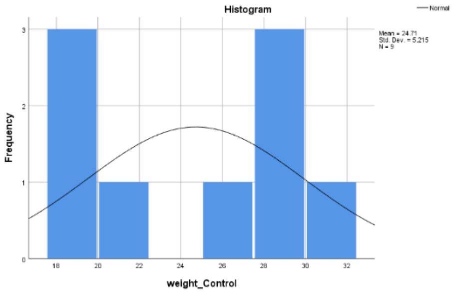


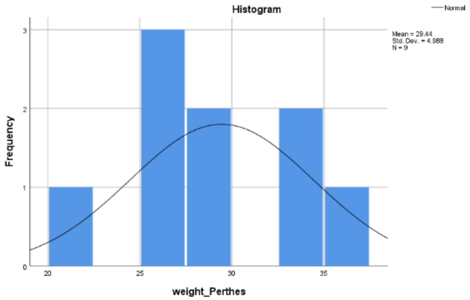


C) Weight

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
weight_Control	.921	9	.398
weight_Perthes	.955	9	.743

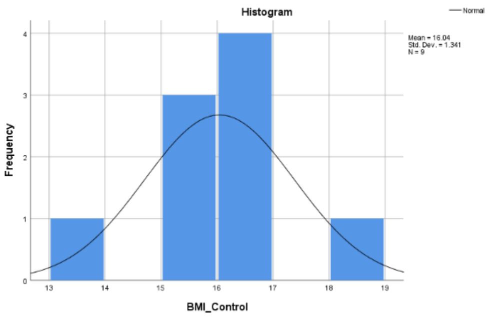


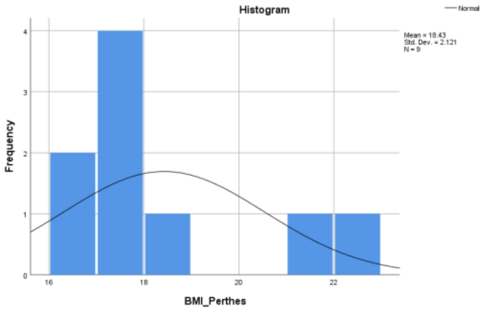


D) BMI

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
BMI_Control	.954	9	.731
BMI_Perthes	.829	9	.044

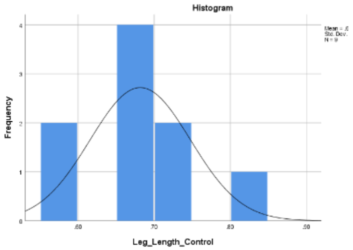


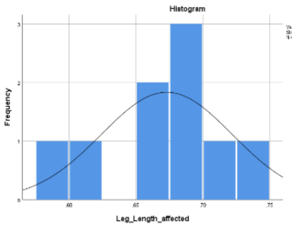


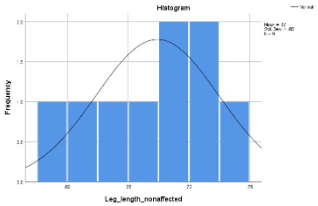
E) Leg Length

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Leg_Length_Control	.963	9	.826
Leg_Length_affected	.928	9	.465
Leg_length_nonaffected	.964	9	.841



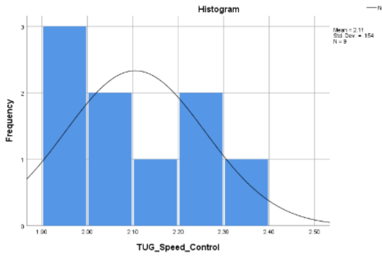


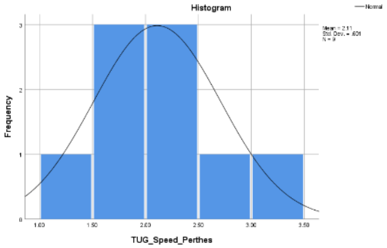


F) TUG Speed

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
TUG_Speed_Control	.931	9	.487
TUG_Speed_Perthes	.875	9	.138



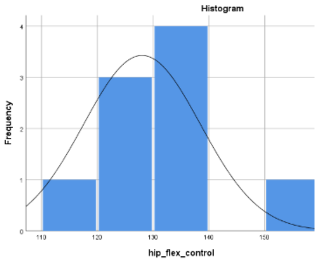


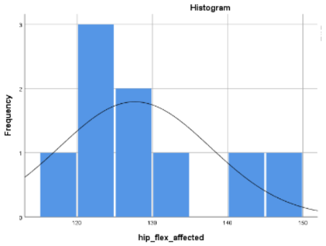
2) Passive Range of Motion (ROM)

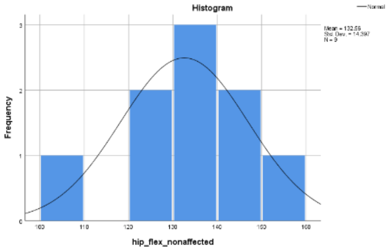
Hip Flexion ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
hip_flex_control	.906	9	.291
hip_flex_affected	.906	9	.286
hip_flex_nonaffected	.975	9	.932



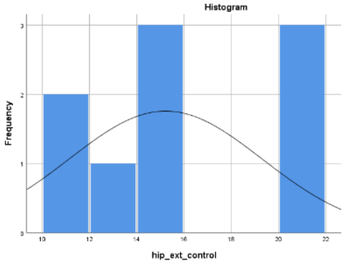


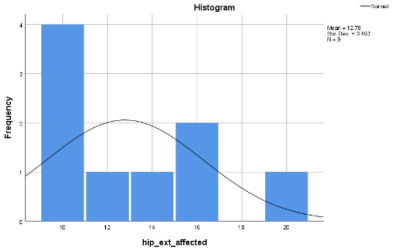


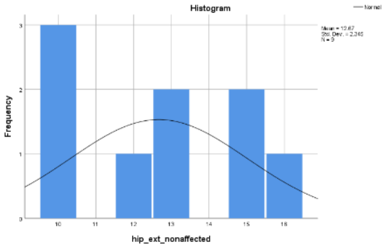
Hip Extension ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
hip_ext_control	.860	9	.095
hip_ext_affected	.808	9	.025
hip_ext_nonaffected	.885	9	.176



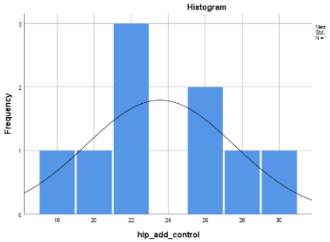


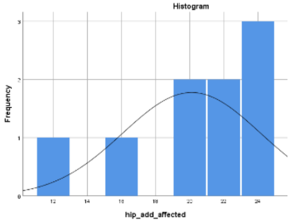


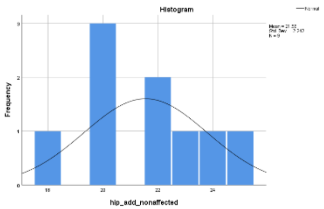
Hip Adduction ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
hip_add_control	.954	9	.735
hip_add_affected	.833	9	.048
hip_add_nonaffected	.956	9	.761



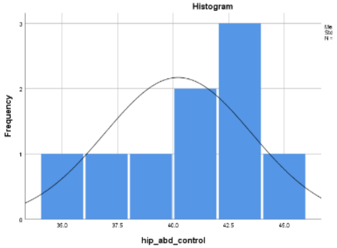


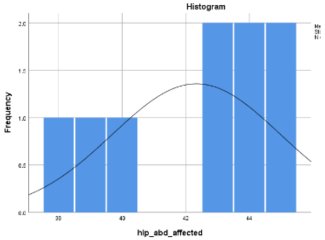


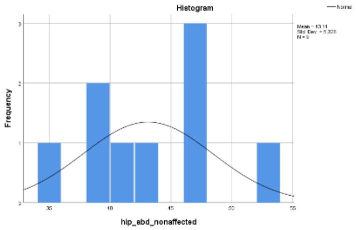
Hip Abduction ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
hip_abd_control	.954	9	.734
hip_abd_affected	.864	9	.105
hip_abd_nonaffected	.960	9	.797



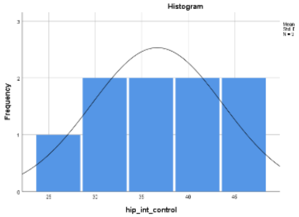


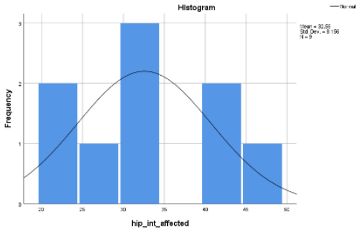


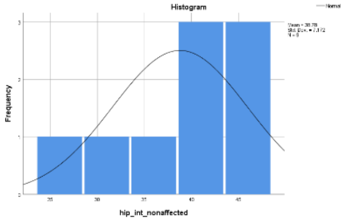
Hip Internal rotation ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
hip_int_control	.945	9	.636
hip_int_affected	.932	9	.498
hip_int_nonaffected	.923	9	.420



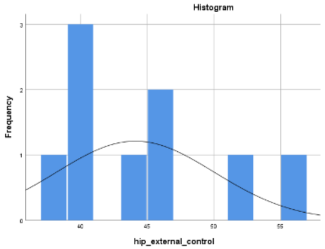


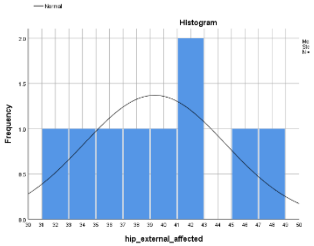


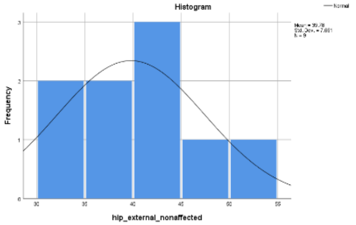
Hip External rotation ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
hip_external_control	.876	9	.144
hip_external_affected	.954	9	.736
hip_external_nonaffected	.923	9	.420



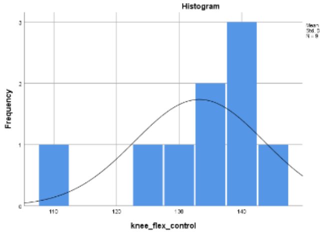


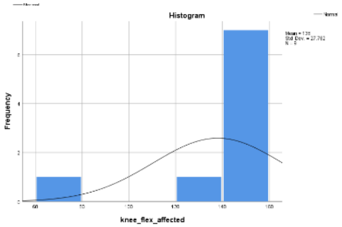


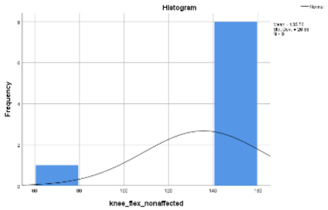
Knee Flexion ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
knee_flex_control	.861	9	.098
knee_flex_affected	.530	9	.000
knee_flex_nonaffected	.553	9	.000



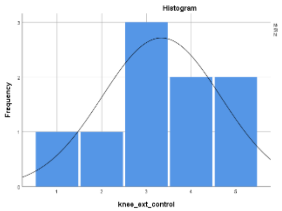


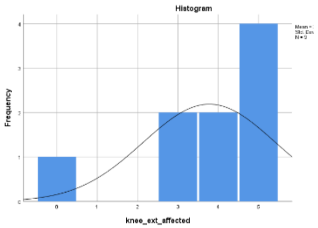


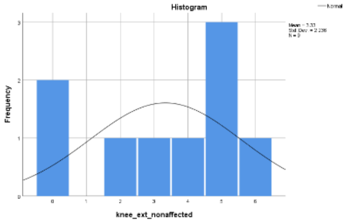
Knee Extension ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
knee_ext_control	.936	9	.545
knee_ext_affected	.774	9	.010
knee_ext_nonaffected	.882	9	.163



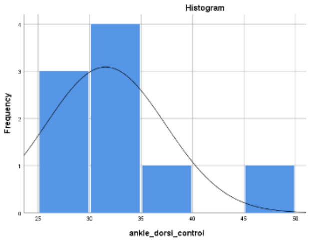


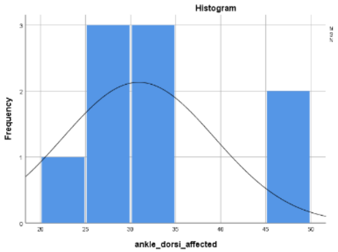


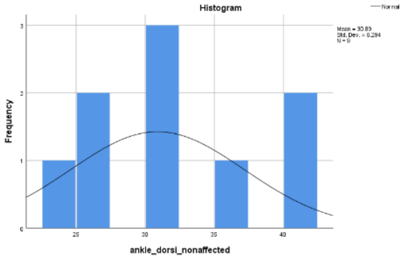
Ankle Dorsiflexion ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
ankle_dorsi_control	.836	9	.053
ankle_dorsi_affected	.771	9	.009
ankle_dorsi_nonaffected	.896	9	.231



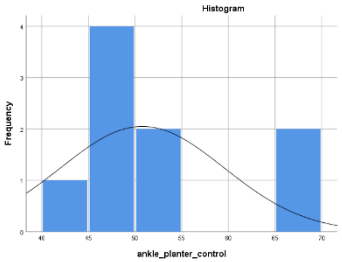


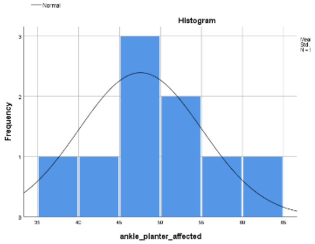


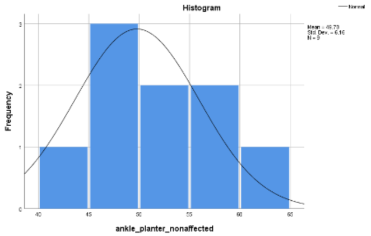
Ankle Plantarflexion ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
ankle_plantar_control	.838	9	.055
ankle_plantar_affected	.984	9	.981
ankle_plantar_nonaffected	.973	9	.921





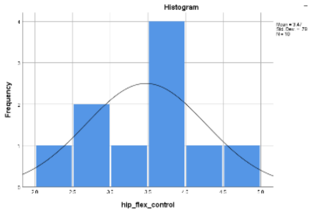


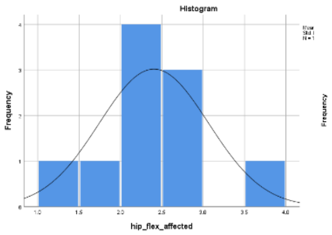
3) Muscle test

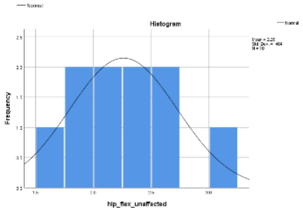
Hip Flexion muscle test

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
hip_flex_control	.979	10	.958
hip_flex_affected	.922	10	.370
hip_flex_unaffected	.974	10	.928



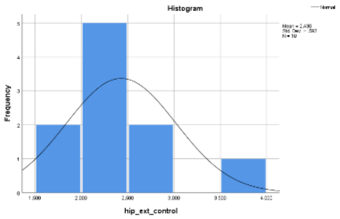


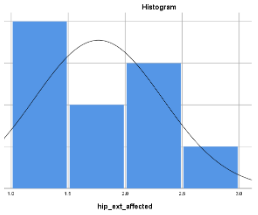


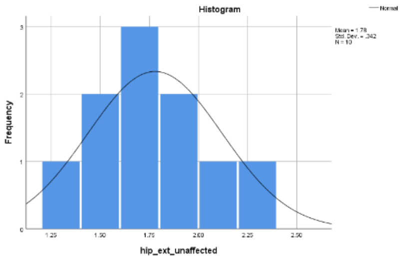
Hip Extension muscle test

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
hip_ext_control	.851	10	.060
hip_ext_affected	.963	10	.821
hip_ext_unaffected	.965	10	.841



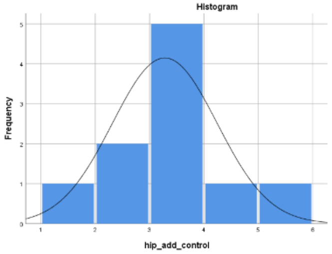


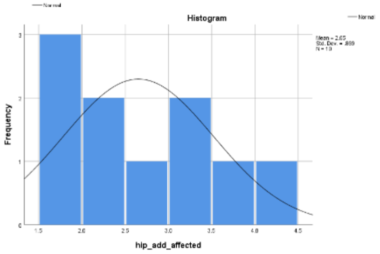


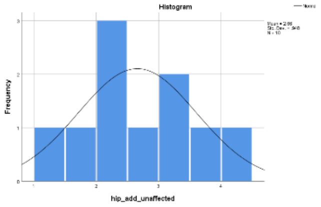
Hip Adduction muscle test

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
hip_add_control	.964	10	.834
hip_add_affected	.964	10	.827
hip_add_unaffected	.981	10	.972



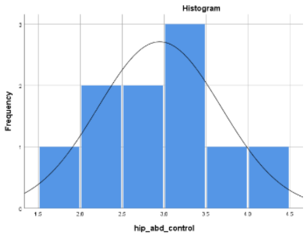


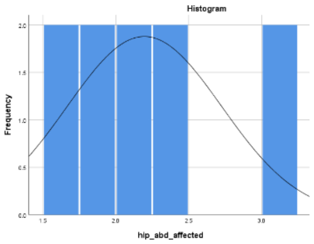


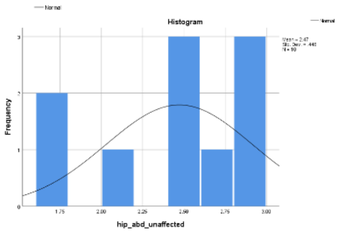
Hip Abduction muscle test

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
hip_abd_control	.960	10	.782
hip_abd_affected	.894	10	.188
hip_abd_unaffected	.900	10	.219



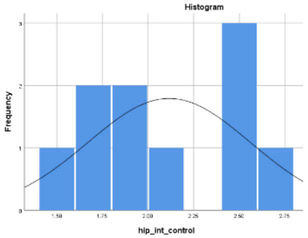


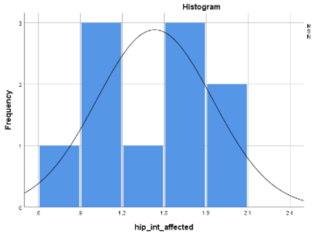


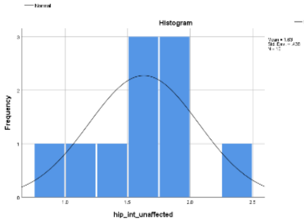
Hip Internal rotation muscle test

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
hip_int_control	.926	10	.412
hip_int_affected	.954	10	.717
hip_int_unaffected	.978	10	.955



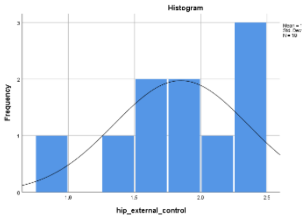


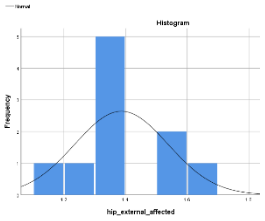


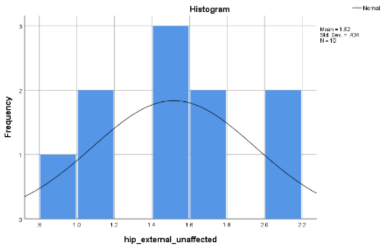
Hip External rotation muscle test

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
hip_external_control	.947	10	.639
hip_external_affected	.922	10	.374
hip_external_unaffected	.960	10	.786



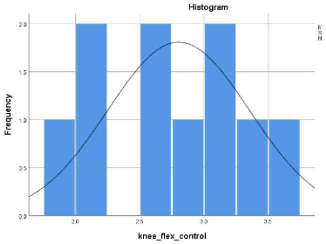


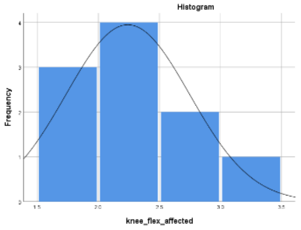


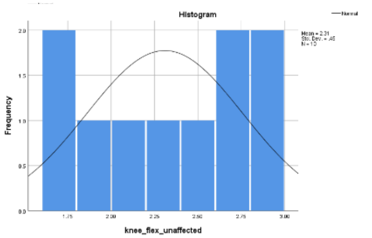
Knee Flexion muscle test

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
knee_flex_control	.956	10	.736
knee_flex_affected	.884	10	.146
knee_flex_unaffected	.924	10	.391



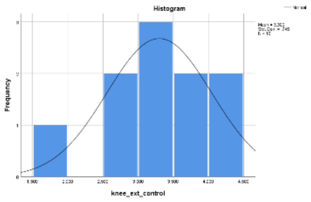


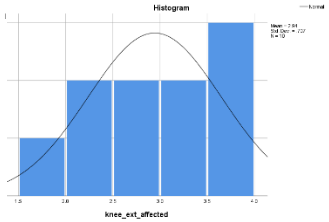


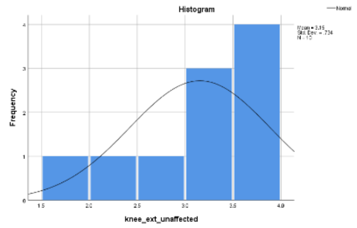
Knee Extension muscle test

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
knee_ext_control	.935	10	.495
knee_ext_affected	.901	10	.223
knee_ext_unaffected	.883	10	.139



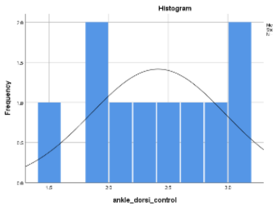


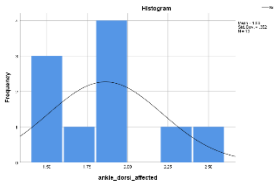


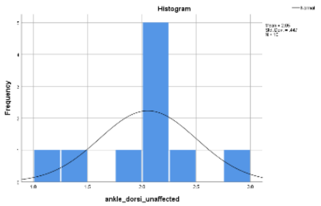
Ankle Dorsiflexion muscle test

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
ankle_dorsi_control	.970	10	.887
ankle_dorsi_affected	.902	10	.229
ankle_dorsi_unaffected	.906	10	.254



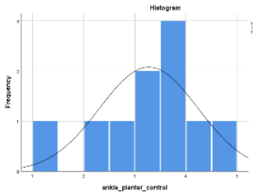


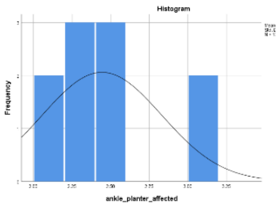


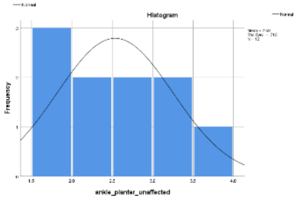
Ankle Plantarflexion muscle test

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
ankle_plantar_control	.973	10	.914
ankle_plantar_affected	.861	10	.078
ankle_plantar_unaffected	.918	10	.340







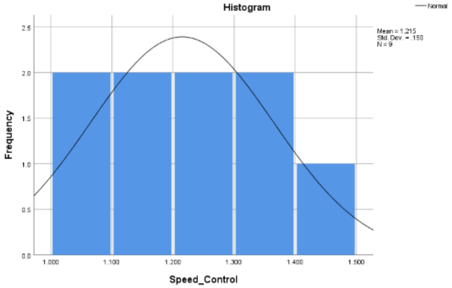
4) Walking Normality test

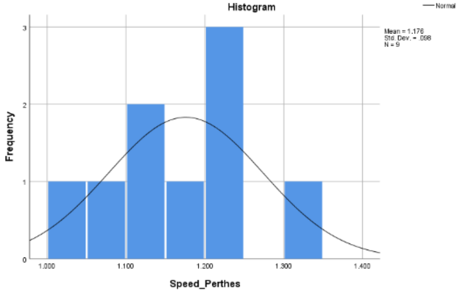
A) Temporospatial parameters

Speed

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Speed_Control	.954	9	.738
Speed_Perthes	.977	9	.946

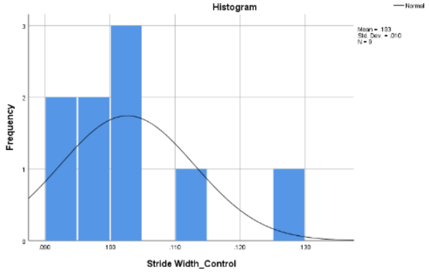


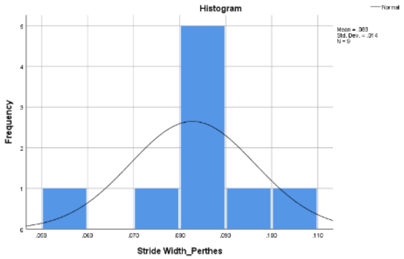


Stride Width

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Stride Width_Control	.878	9	.151
Stride Width_Perthes	.900	9	.254

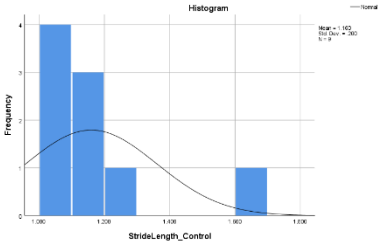


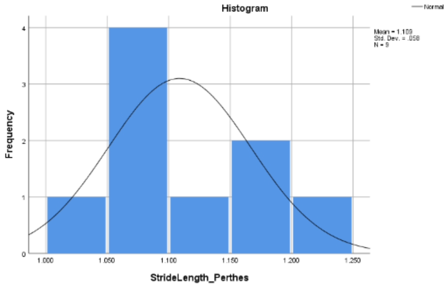


Stride length

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
StrideLength_Control	.713	9	.002
StrideLength_Perthes	.924	9	.429

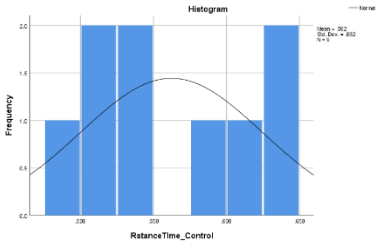


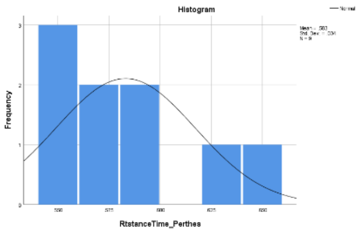


Right Stance Time

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
RstanceTime_Control	.900	9	.251
RtstanceTime_Perthes	.878	9	.150

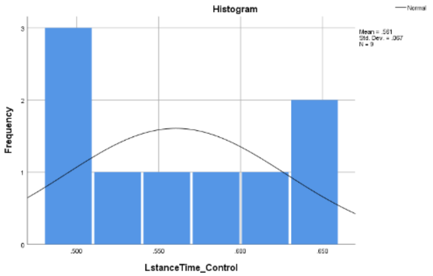


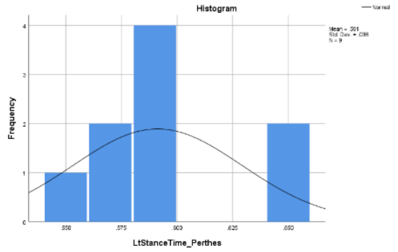


Left Stance Time

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
LstanceTime_Control	.875	9	.140
LtStanceTime_Perthes	.862	9	.100

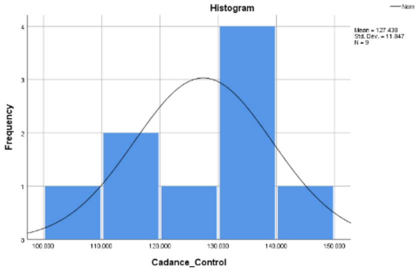


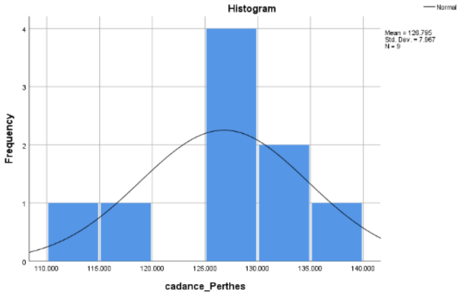


Cadence

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Cadance_Control	.950	9	.693
cadance_Perthes	.894	9	.220



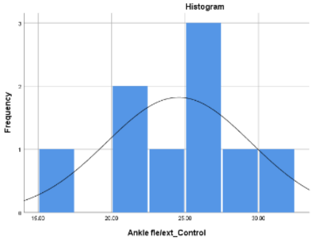


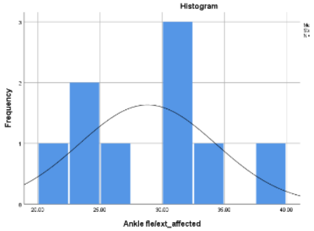
Walking Kinematic Normality Test

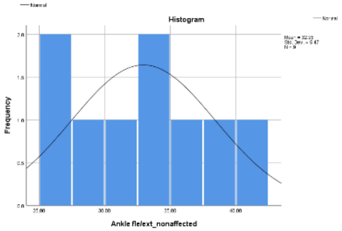
Ankle flex/ext ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Ankle fle/ext_Control	.971	9	.906
Ankle fle/ext_affected	.969	9	.884
Ankle fle/ext_nonaffected	.950	9	.695



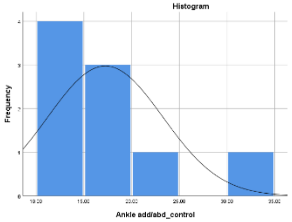


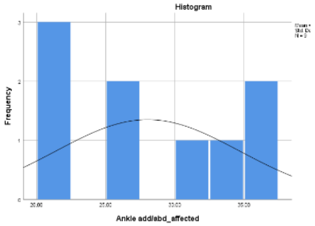


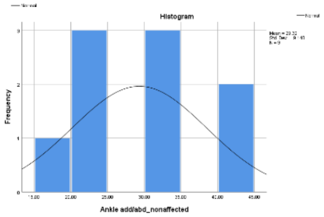
Ankle add/abd ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Ankle add/abd_control	.890	9	.199
Ankle add/abd_affected	.894	9	.217
Ankle add/abd_nonaffected	.848	9	.072



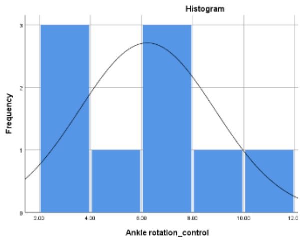


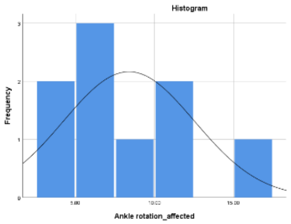


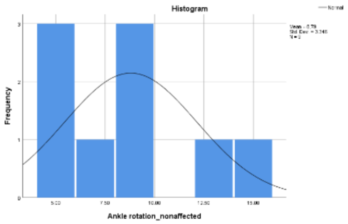
Ankle rotation ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Ankle rotation_control	.926	9	.445
Ankle rotation_affected	.934	9	.516
Ankle rotation_nonaffected	.940	9	.582



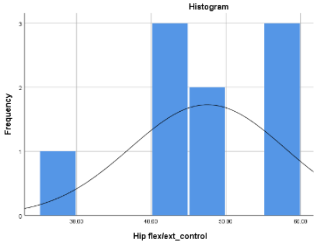


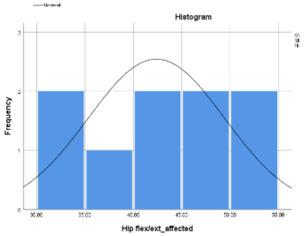


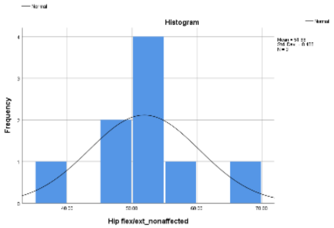
Hip flex/ext ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Hip flex/ext_control	.907	9	.294
Hip flex/ext_affected	.944	9	.629
Hip flex/ext_nonaffected	.944	9	.621



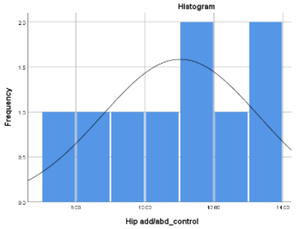


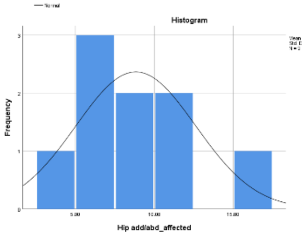


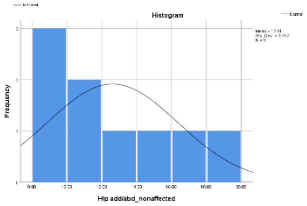
Hip add/abd ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Hip add/abd_control	.945	9	.631
Hip add/abd_affected	.937	9	.552
Hip add/abd_nonaffected	.910	9	.314



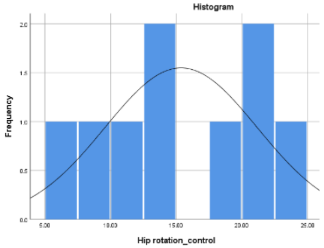


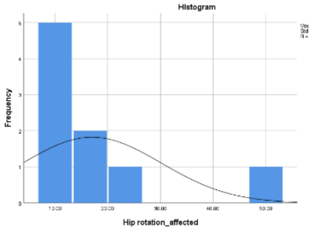


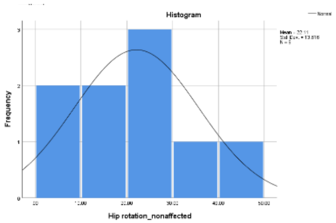
Hip rotation ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Hip rotation_control	.953	9	.727
Hip rotation_affected	.667	9	.001
Hip rotation_nonaffected	.959	9	.792



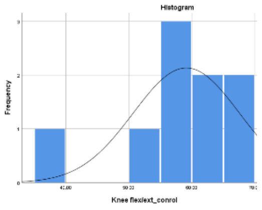


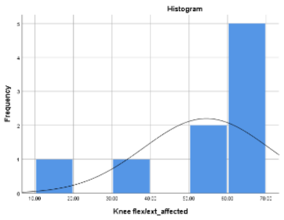


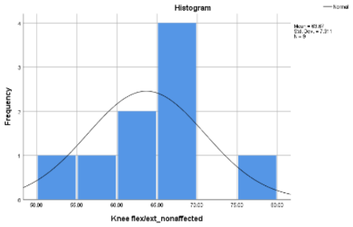
Knee flex/ext ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Knee flex/ext_conrol	.841	9	.059
Knee flex/ext_affected	.843	9	.063
Knee flex/ext_nonaffected	.968	9	.876



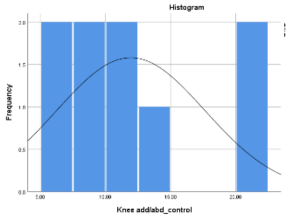


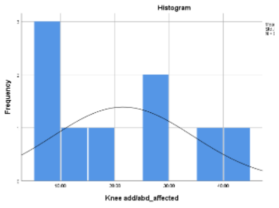


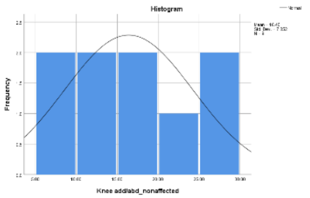
Knee add/abd ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Knee add/abd_control	.876	9	.142
Knee add/abd_affected	.880	9	.156
Knee add/abd_nonaffected	.940	9	.584



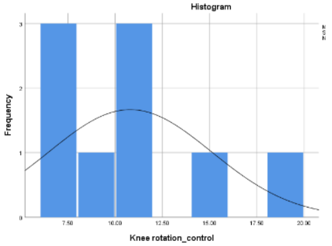


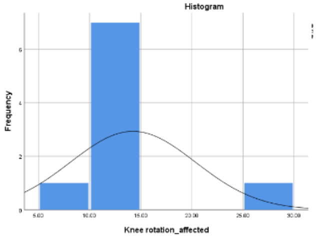


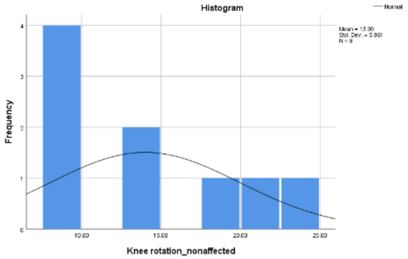
Knee rotation ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Knee rotation_control	.901	9	.258
Knee rotation_affected	.658	9	.000
Knee rotation_nonaffected	.872	9	.129



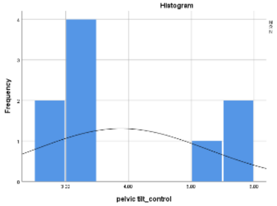


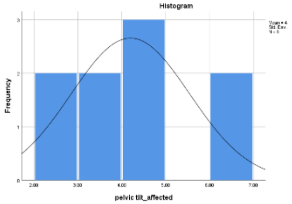


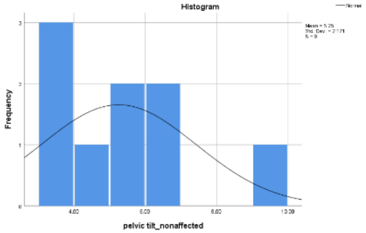
Pelvic tilt flexion ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
pelvic tilt_control	.806	9	.024
pelvic tilt_affected	.958	9	.775
pelvic tilt_nonaffected	.878	9	.150



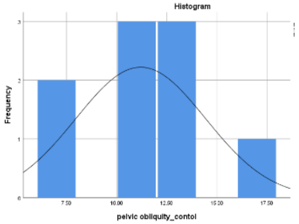


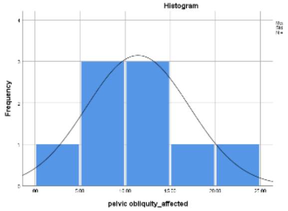


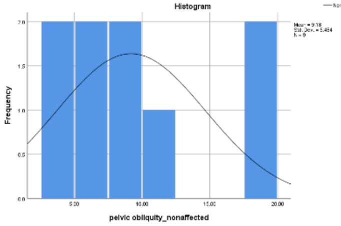
Pelvic obliquity ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
pelvic obliquity_contol	.904	9	.273
pelvic obliquity_affected	.899	9	.246
pelvic obliquity_nonaffected	.883	9	.169



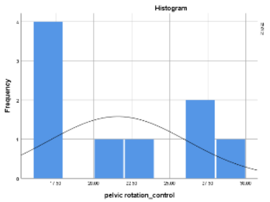


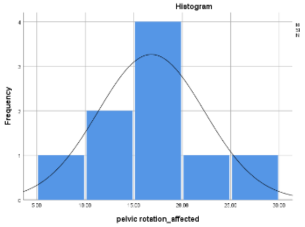


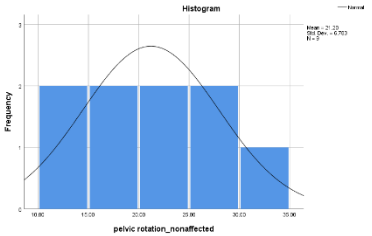
Pelvic rotation ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
pelvic rotation_control	.853	9	.080
pelvic rotation_affected	.935	9	.532
pelvic rotation_nonaffected	.986	9	.988



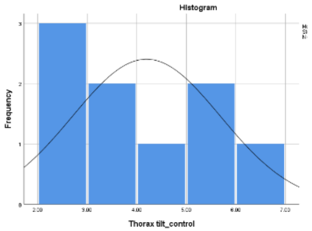


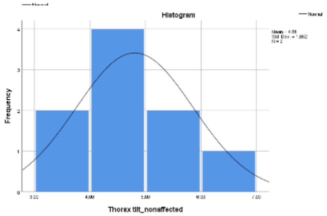


Trunk tilt ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Thorax tilt_control	.847	9	.070
Thorax tilt_nonaffected	.976	9	.942

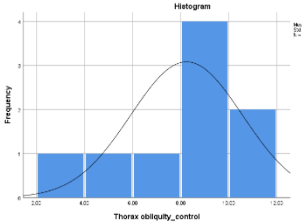


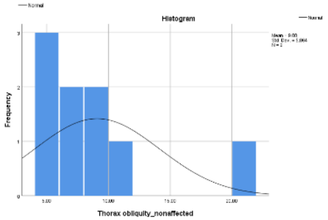


Trunk obliquity ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Thorax obliquity_control	.925	9	.435
Thorax obliquity_nonaffected	.735	9	.004

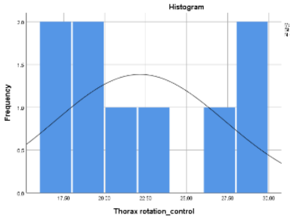


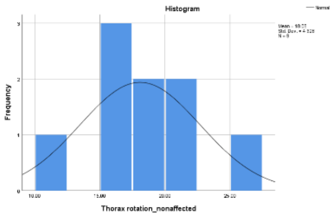


Trunk rotation ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Thorax rotation_control	.882	9	.164
Thorax rotation_nonaffected	.982	9	.974



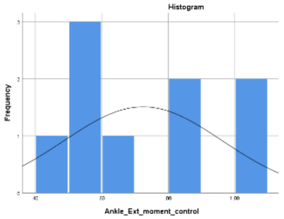


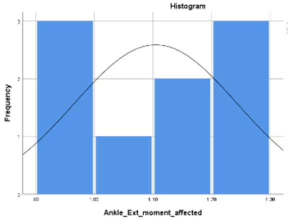
Kinetic Parameters normality test

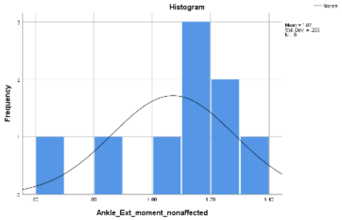
Ankle Extensor moment

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Ankle_Ext_moment_control	.887	9	.188
Ankle_Ext_moment_affected	.918	9	.373
Ankle_Ext_moment_nonaffected	.878	9	.149



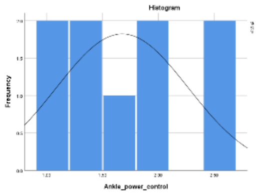


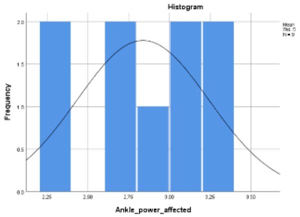


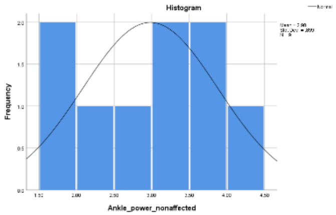
Ankle power

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Ankle_power_control	.934	9	.516
Ankle_power_affected	.897	9	.233
Ankle_power_nonaffected	.915	9	.351



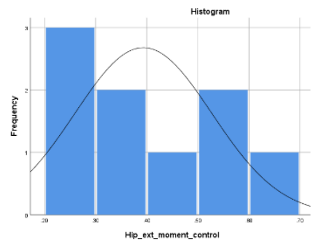


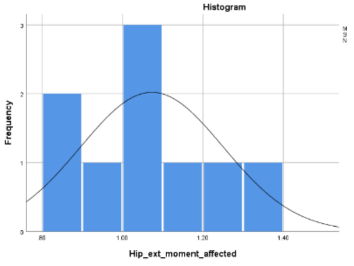


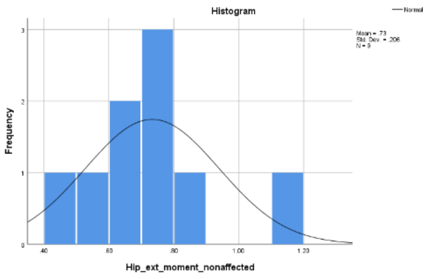
Hip extensor moment

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Hip_ext_moment_control	.896	9	.229
Hip_ext_moment_affected	.943	9	.612
Hip_ext_moment_nonaffected	.941	9	.591



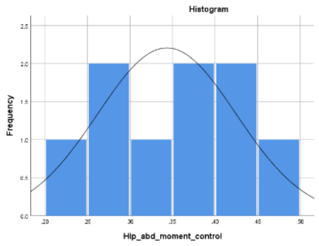


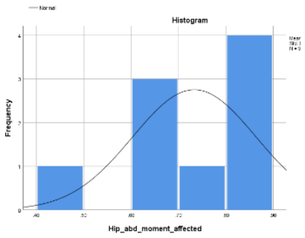


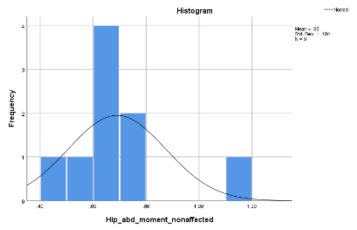
Hip abductor moment

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Hip_abd_moment_control	.946	9	.651
Hip_abd_moment_affected	.932	9	.499
Hip_abd_moment_nonaffected	.871	9	.127



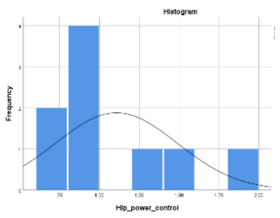


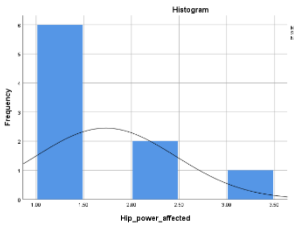


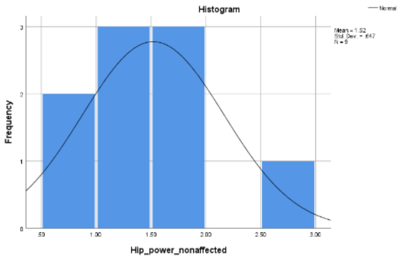
Hip Power

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Hip_power_control	.860	9	.095
Hip_power_affected	.805	9	.024
Hip_power_nonaffected	.936	9	.542



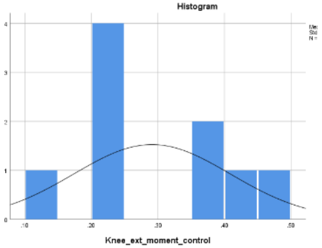


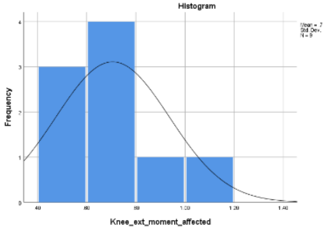


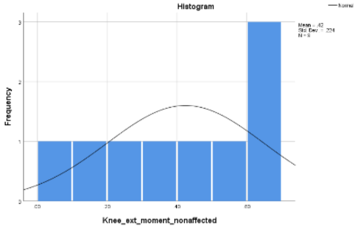
Knee extensor moment

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Knee_ext_moment_control	.917	9	.364
Knee_ext_moment_affected	.925	9	.438
Knee_ext_moment_nonaffected	.938	9	.564



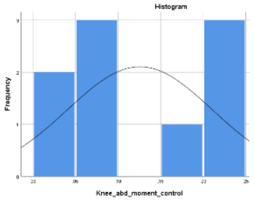


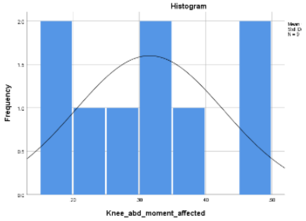


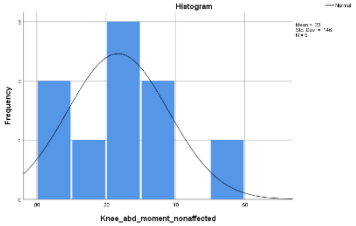
Knee abductor moment

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Knee_abd_moment_control	.835	9	.051
Knee_abd_moment_affected	.912	9	.329
Knee_abd_moment_nonaffected	.923	9	.415



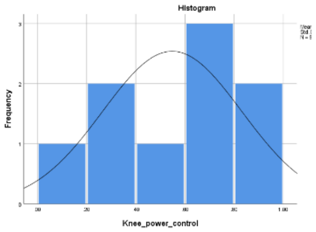


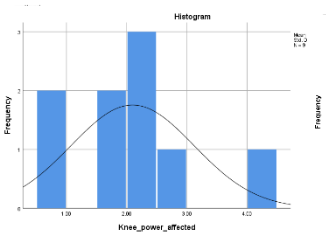


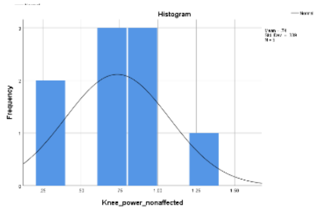
Knee power

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Knee_power_control	.917	9	.371
Knee_power_affected	.920	9	.390
Knee_power_nonaffected	.940	9	.586



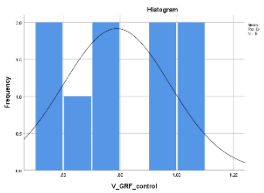


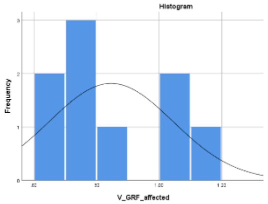


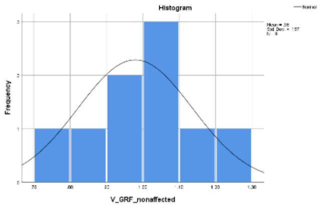
Vertical GRF

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
V_GRF_control	.928	9	.464
V_GRF_affected	.899	9	.247
V_GRF_nonaffected	.965	9	.844





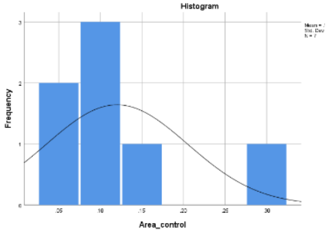


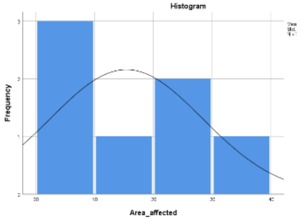
5) Single leg balance normality test

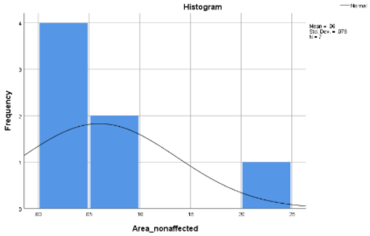
COP_Area

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Area_control	.782	7	.027
Area_affected	.870	7	.184
Area_nonaffected	.781	7	.027



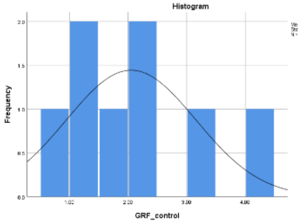


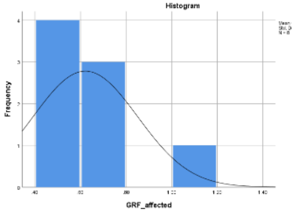


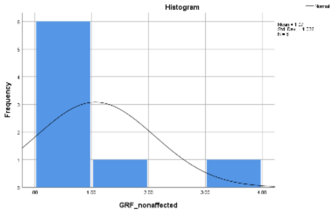
Vertical_GRF

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
GRF_control	.932	8	.533
GRF_affected	.865	8	.134
GRF_nonaffected	.680	8	.001



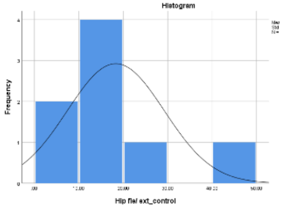


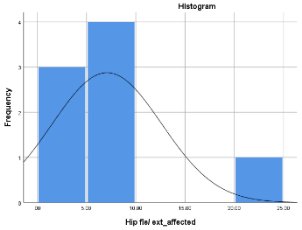


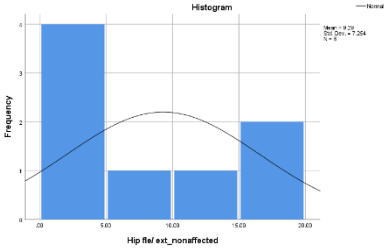
Hip flex/extension ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Hip fle/ ext_control	.935	8	.563
Hip fle/ ext_affected	.702	8	.002
Hip fle/ ext_nonaffected	.838	8	.071



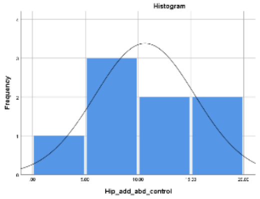


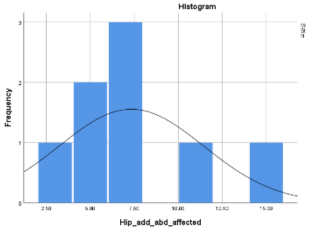


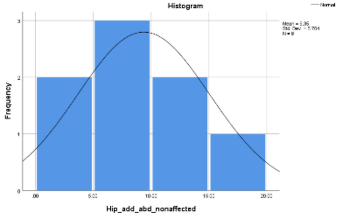
Hip add/abduction ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Hip_add_abd_control	.972	8	.912
Hip_add_abd_affected	.945	8	.661
Hip_add_abd_nonaffected	.933	8	.542

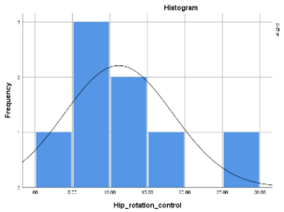


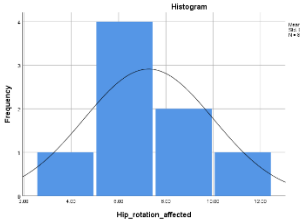


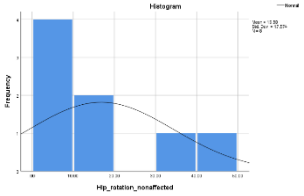


Hip rotation ROM

	Shapiro-Wilk		
	Statistic	df	Sig.
Hip_rotation_control	.883	8	.200
Hip_rotation_affected	.915	8	.392
Hip_rotation_nonaffected	.797	8	.027



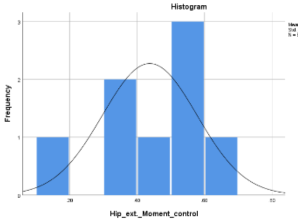


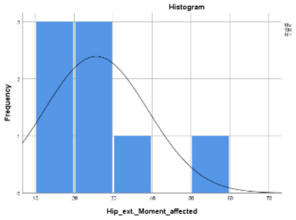


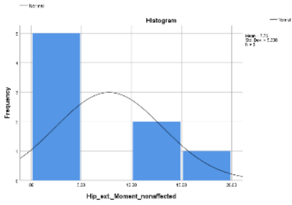
Hip extensor moment

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Hip_ext._Moment_control	.951	8	.722
Hip_ext._Moment_affected	.874	8	.165
Hip_ext._Moment_nonaffected	.777	8	.016



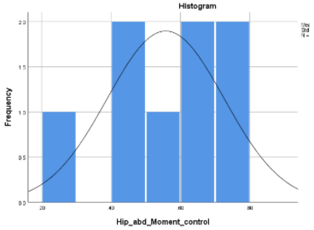


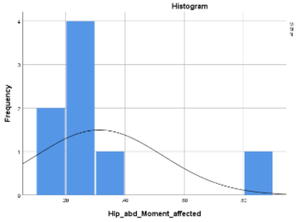


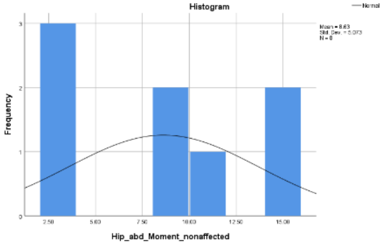
Hip abductor moment

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Hip_abd_Moment_control	.908	8	.343
Hip_abd_Moment_affected	.690	8	.002
Hip_abd_Moment_nonaffected	.913	8	.375



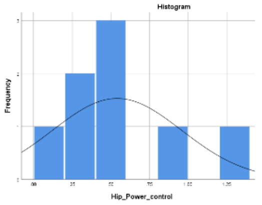


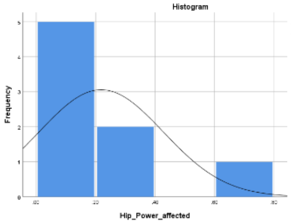


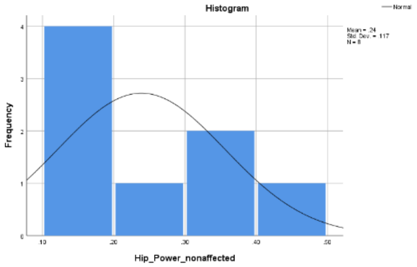
Hip power

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Hip_Power_control	.851	8	.098
Hip_Power_affected	.628	8	.000
Hip_Power_nonaffected	.891	8	.239



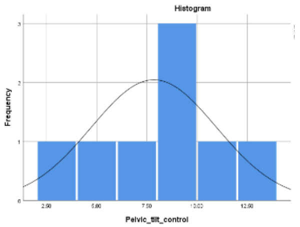


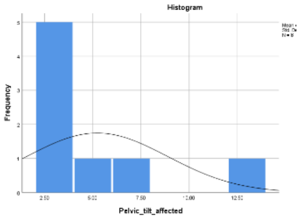


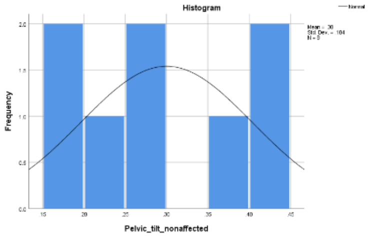
Pelvic tilt ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Pelvic_tilt_control	.953	8	.737
Pelvic_tilt_affected	.744	8	.007
Pelvic_tilt_nonaffected	.901	8	.294



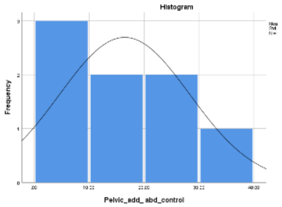


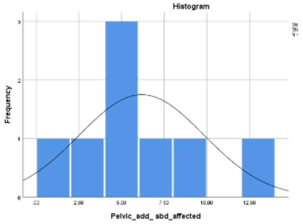


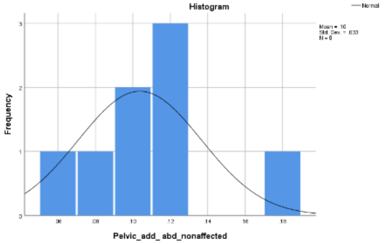
Pelvic obliquity ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Pelvic_add_ abd_control	.928	8	.498
Pelvic_add_ abd_affected	.921	8	.441
Pelvic_add_ abd_nonaffected	.876	8	.172



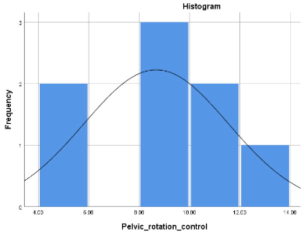


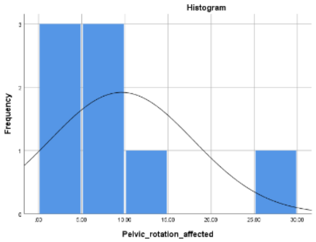


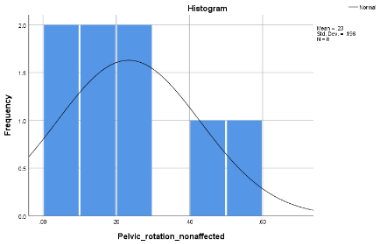
Pelvic rotation ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Pelvic_rotation_control	.945	8	.657
Pelvic_rotation_affected	.764	8	.012
Pelvic_rotation_nonaffected	.922	8	.444



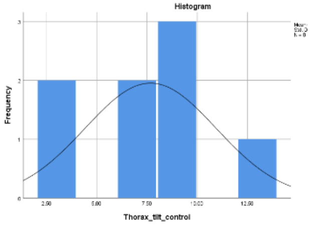


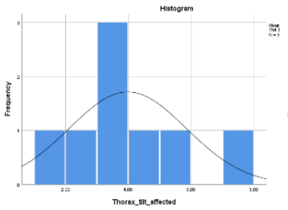


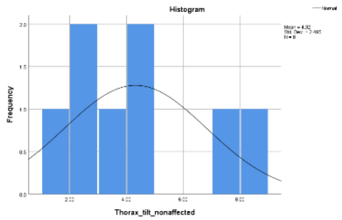
Trunk tilt ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Thorax_tilt_control	.949	8	.703
Thorax_tilt_affected	.923	8	.451
Thorax_tilt_nonaffected	.889	8	.227



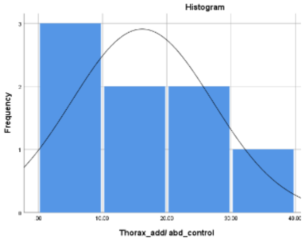


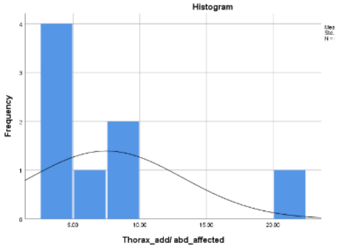


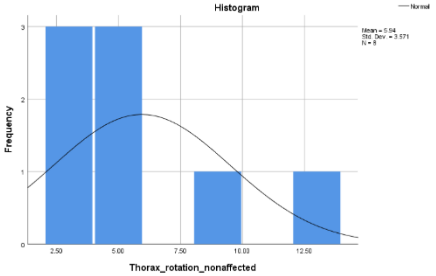
Trunk obliquity ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Thorax_add/ abd_control	.931	8	.521
Thorax_add/ abd_affected	.774	8	.015
Thorax_rotation_nonaffected	.812	8	.039



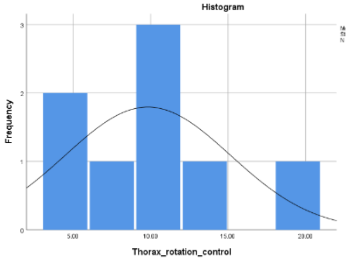


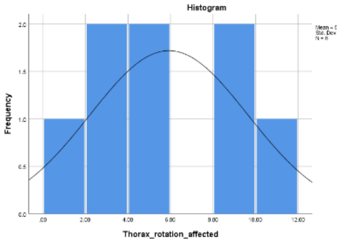


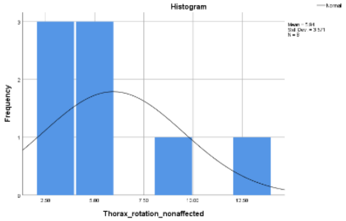
Trunk rotation ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Thorax_rotation_control	.908	8	.341
Thorax_rotation_affected	.913	8	.372
Thorax_rotation_nonaffected	.812	8	.039





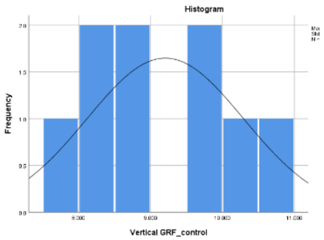


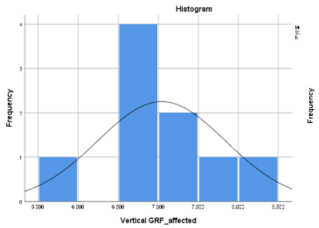
6) Squat activity normality test

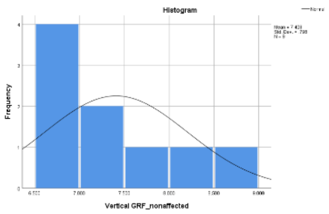
Vertical_GRF

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Vertical GRF_control	.941	9	.588
Vertical GRF_affected	.930	9	.485
Vertical GRF_nonaffected	.849	9	.073



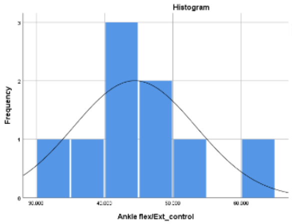


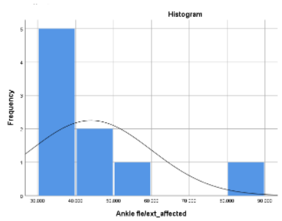


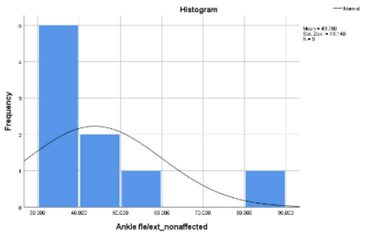
Ankle dorsi/plantarflexion ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Ankle flex/Ext_control	.974	9	.930
Ankle fle/ext_affected	.748	9	.005
Ankle fle/ext_nonaffected	.747	9	.005



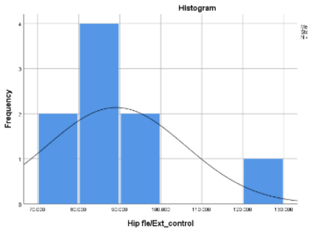


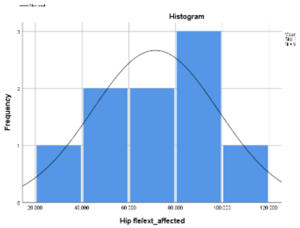


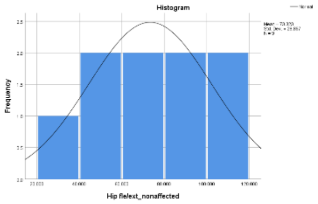
Hip flex/extension ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Hip fle/Ext_control	.802	9	.022
Hip fle/ext_affected	.972	9	.913
Hip fle/ext_nonaffected	.934	9	.518



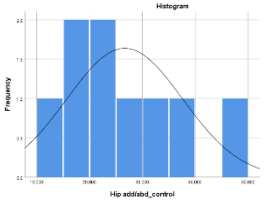


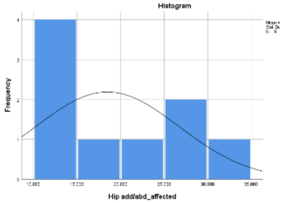


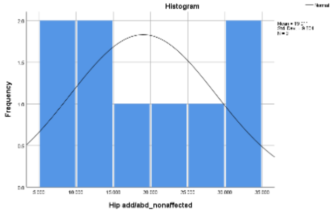
Hip add/abduction ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Hip add/abd_control	.924	9	.430
Hip add/abd_affected	.839	9	.057
Hip add/abd_nonaffected	.883	9	.168



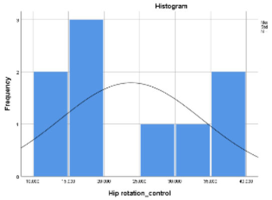


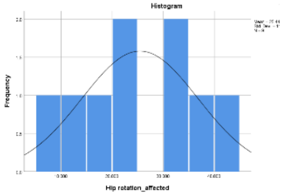


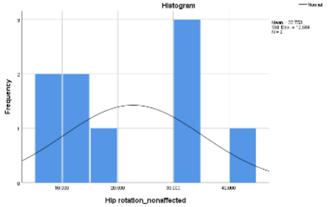
Hip rotation ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Hip rotation_control	.853	9	.080
Hip rotation_affected	.941	9	.593
Hip rotation_nonaffected	.900	9	.254



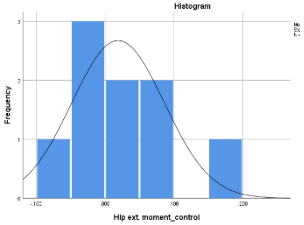


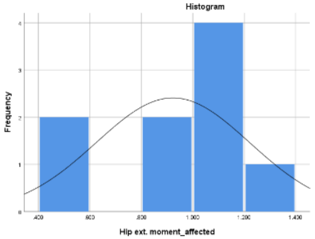


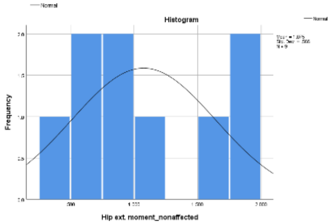
Hip extensor moment

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Hip ext. moment_control	.942	9	.601
Hip ext. moment_affected	.940	9	.583
Hip ext. moment_nonaffected	.900	9	.250



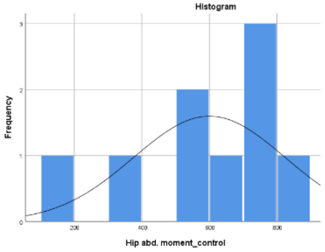


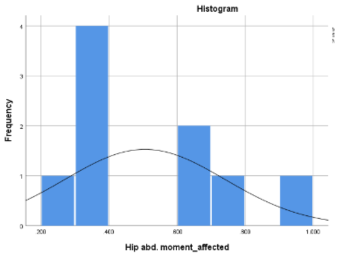


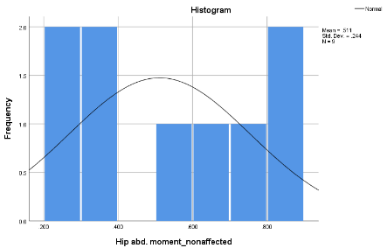
Hip abductor moment

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Hip abd. moment_control	.886	9	.181
Hip abd. moment_affected	.855	9	.085
Hip abd. moment_nonaffected	.899	9	.248



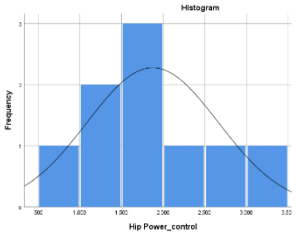


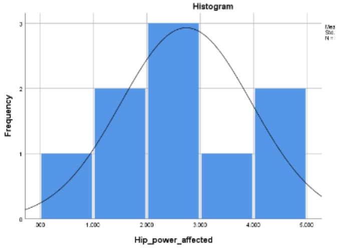


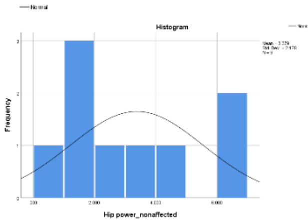
Hip power

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Hip Power_control	.981	9	.971
Hip_power_affected	.961	9	.807
Hip power_nonaffected	.906	9	.288



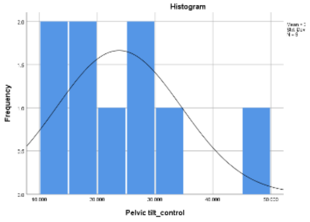


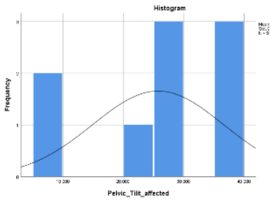


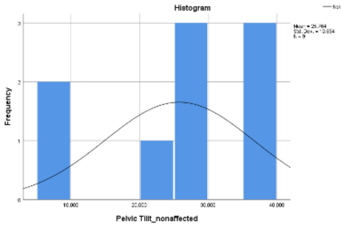
Pelvic tilt ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Pelvic tilt_control	.942	9	.607
Pelvic_Tilit_affected	.880	9	.157
Pelvic Tilit_nonaffected	.880	9	.157



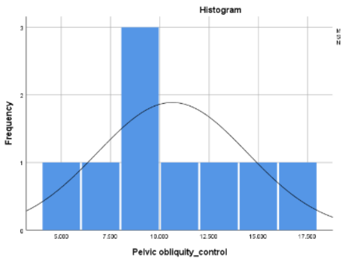


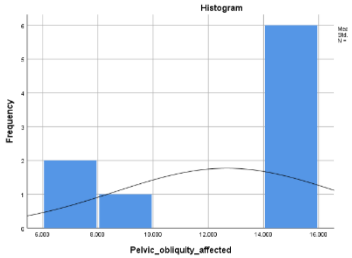


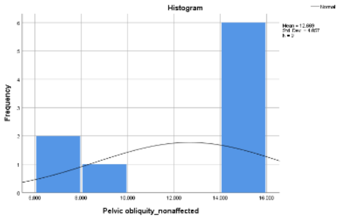
Pelvic obliquity ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Pelvic obliquity_control	.946	9	.644
Pelvic_obliquity_affected	.724	9	.003
Pelvic obliquity_nonaffected	.724	9	.003



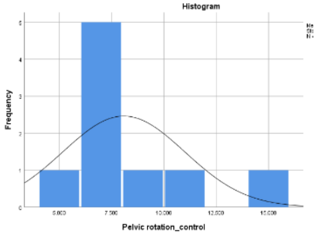


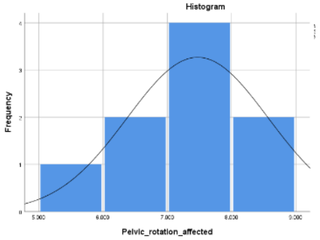


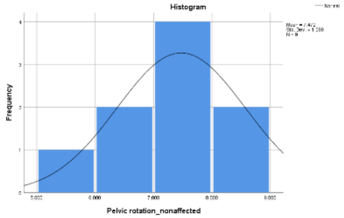
Pelvic rotation ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Pelvic rotation_control	.871	9	.127
Pelvic_rotation_affected	.908	9	.302
Pelvic rotation_nonaffected	.908	9	.302



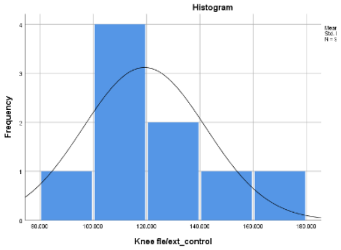


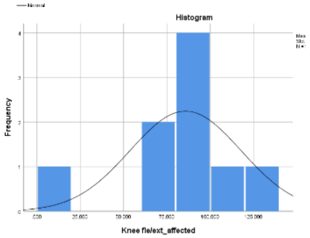


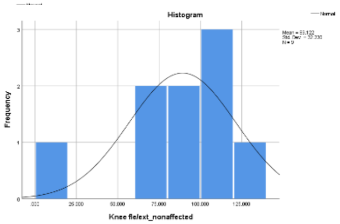
Knee flex/extension ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Knee fle/ext_control	.980	9	.966
Knee fle/ext_affected	.878	9	.151
Knee fle/ext_nonaffected	.831	9	.046



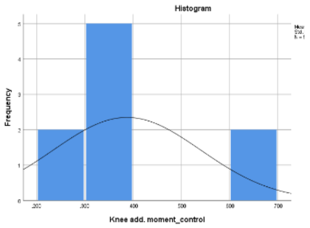


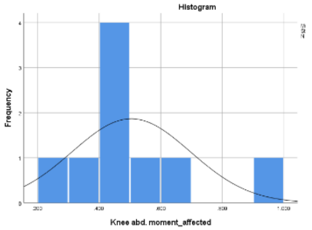


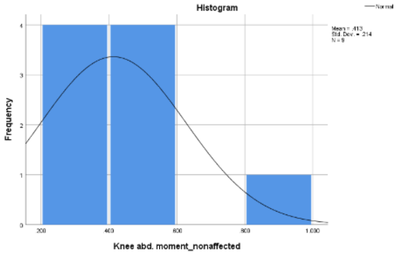
Knee abductor moment

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Knee add. moment_control	.794	9	.018
Knee abd. moment_affected	.918	9	.374
Knee abd. moment_nonaffected	.806	9	.024



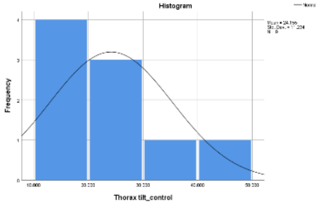


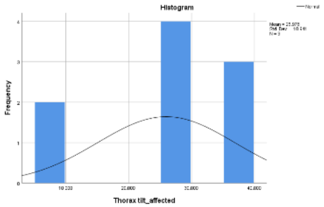


Trunk tilt ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Thorax tilt_control	.934	9	.521
Thorax tilt_affected	.883	9	.170

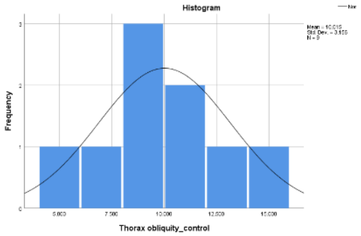


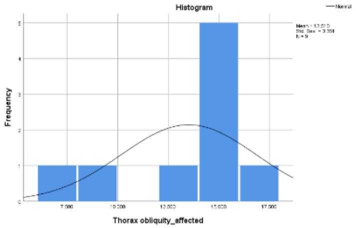


Trunk obliquity ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Thorax obliquity_control	.977	9	.945
Thorax obliquity_affected	.796	9	.018

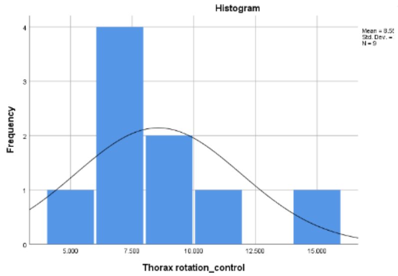


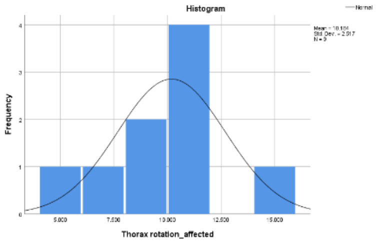


Trunk rotation ROM

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Thorax rotation_control	.848	9	.071
Thorax rotation_affected	.938	9	.561



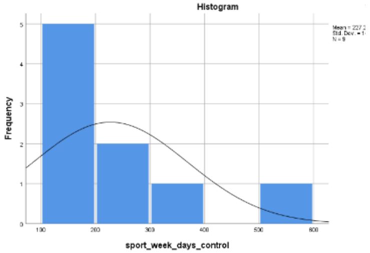


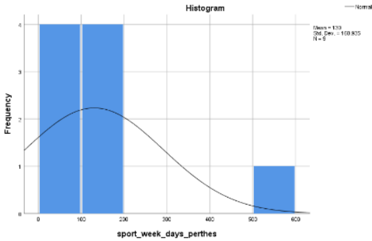
7) Physical activity questionnaire (C_PAQ) normality test

Sport activity

Tests of Normality

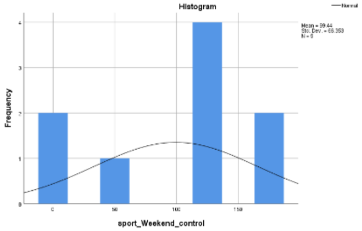
	Shapiro-Wilk		
	Statistic	df	Sig.
sport_week_days_control	.854	9	.082
sport_week_days_perthes	.744	9	.005

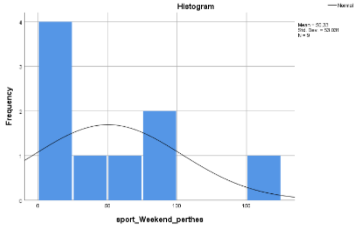




Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
sport_Weekend_control	.866	9	.110
sport_Weekend_perthes	.871	9	.125

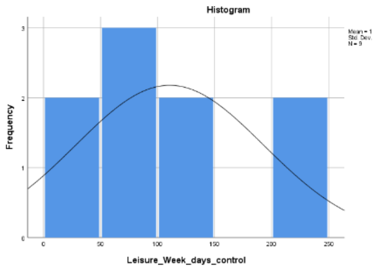


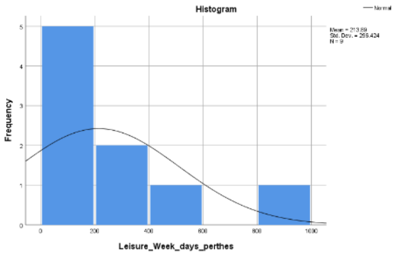


Leisure time activity

Tests of Normality

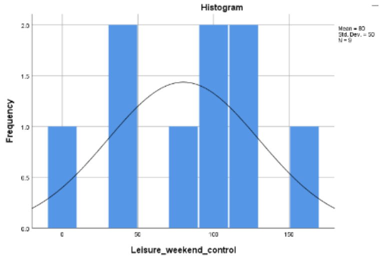
	Shapiro-Wilk		
	Statistic	df	Sig.
Leisure_Week_days_control	.896	9	.230
Leisure_Week_days_perthes	.765	9	.008

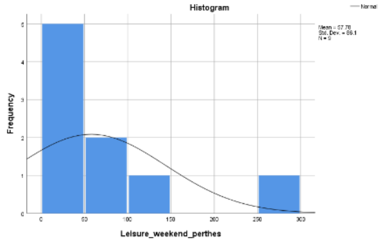




Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Leisure_weekend_control	.941	9	.598
Leisure_weekend_perthes	.727	9	.003

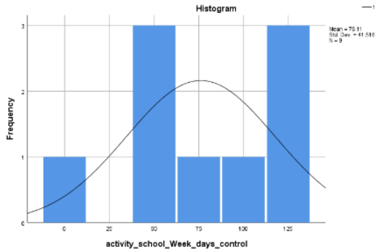


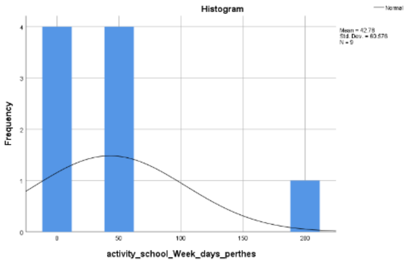


Activity at school

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
activity_school_Week_days_control	.893	9	.215
activity_school_Week_days_perthes	.721	9	.003

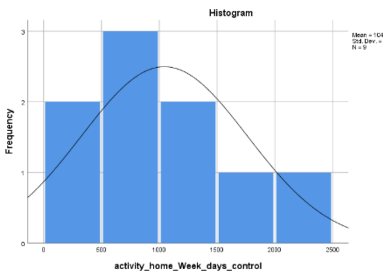


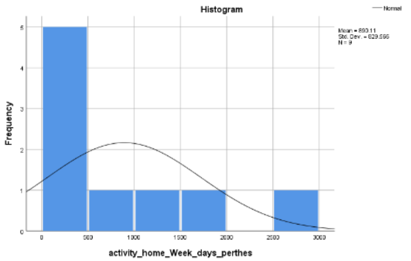


Activity at home

Tests of Normality

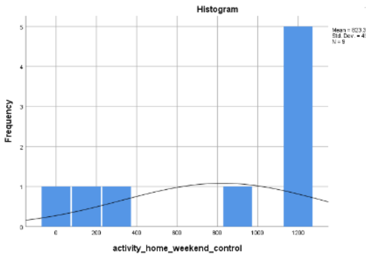
	Shapiro-Wilk		
	Statistic	df	Sig.
activity_home_Week_days_control	.907	9	.298
activity_home_Week_days_perthes	.789	9	.015

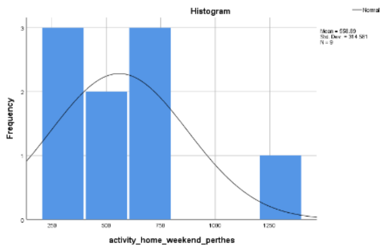




Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
activity_home_weekend_control	.790	9	.016
activity_home_weekend_perthes	.894	9	.217



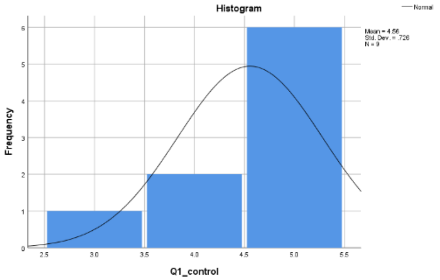


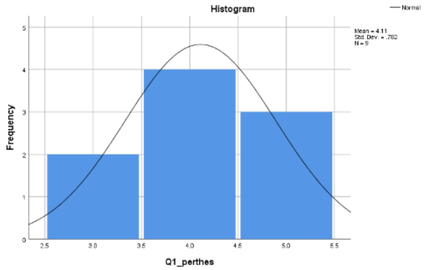
8) Quality of life questionnaire normality test

Question 1

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Q1_control	.684	9	.001
Q1_perthes	.838	9	.055

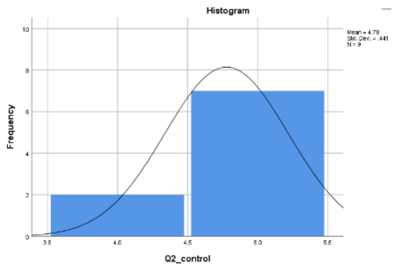


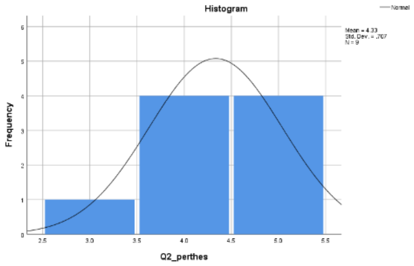


Question 2

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Q2_control	.536	9	.000
Q2_perthes	.805	9	.024

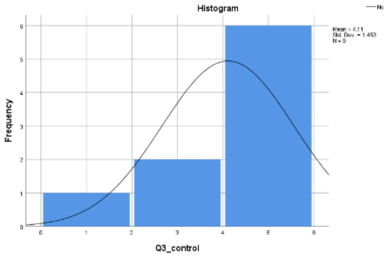


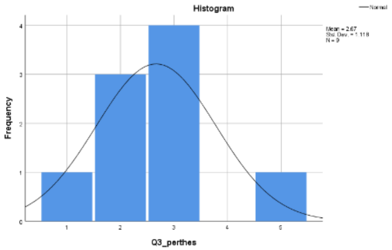


Question 3

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Q3_control	.684	9	.001
Q3_perthes	.883	9	.170

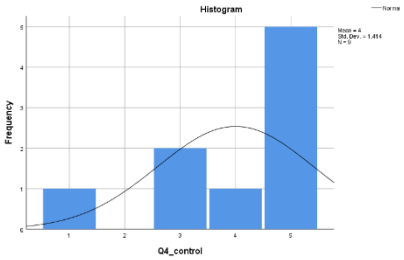


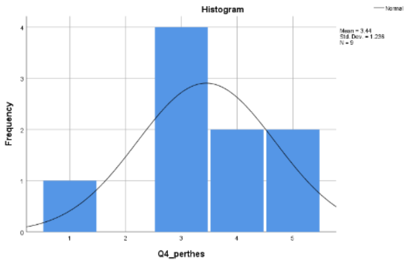


Question 4

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Q4_control	.763	9	.008
Q4_perthes	.889	9	.195

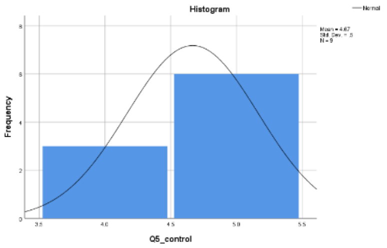


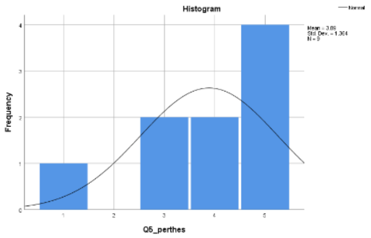


Question 5

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Q5_control	.617	9	.000
Q5_perthes	.820	9	.035

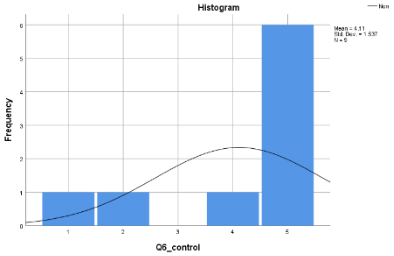


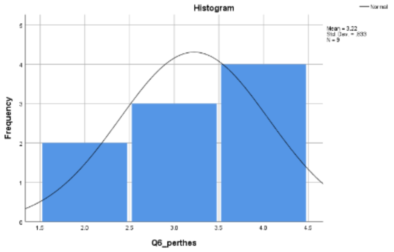


Question 6

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Q6_control	.658	9	.000
Q6_perthes	.808	9	.025

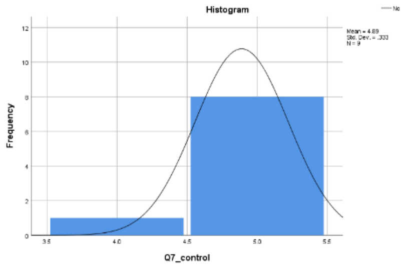


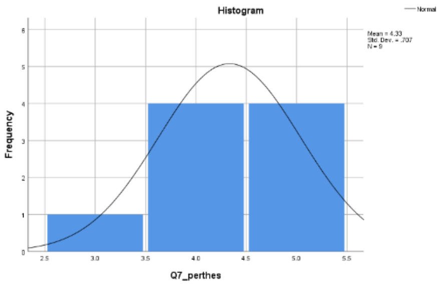


Question 7

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Q7_control	.390	9	.000
Q7_perthes	.805	9	.024

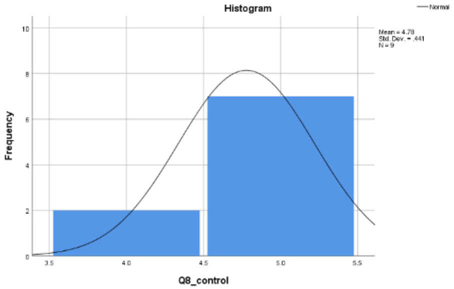


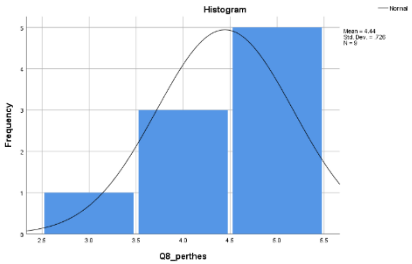


Question 8

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Q8_control	.536	9	.000
Q8_perthes	.763	9	.008

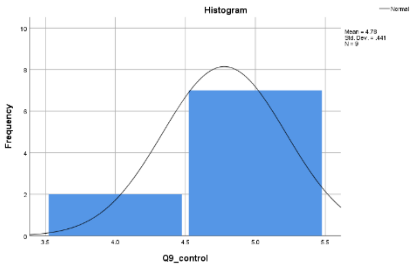


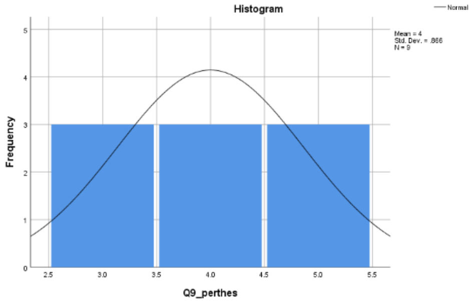


Question 9

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Q9_control	.536	9	.000
Q9_perthes	.823	9	.037

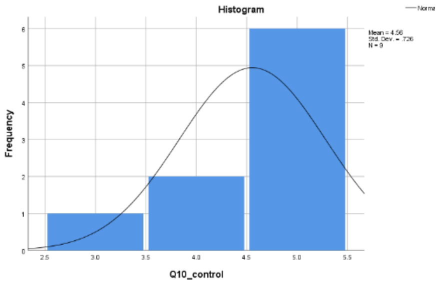


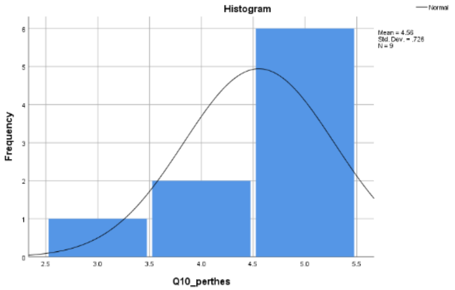


Question 10

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Q10_control	.684	9	.001
Q10_perthes	.684	9	.001

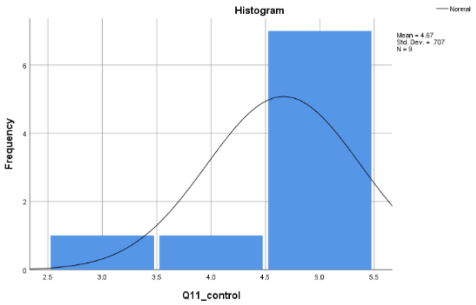


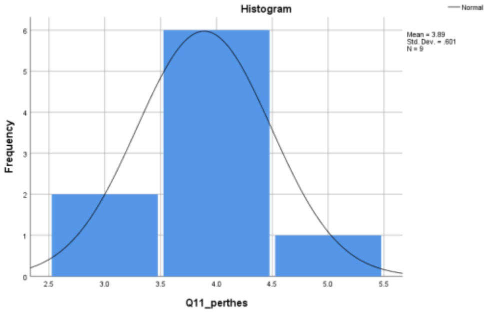


Question 11

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Q11_control	.564	9	.000
Q11_perthes	.781	9	.012





Appendix xxiv: Reliability Data

1) Reliability of placing the marker on static position for typically developing children

Reliability of placing the marker on static position

Subject	Session1																Session2															
	LASI	RASI	LPSI	RPSI	LTHI	LKNE	LTIB	LANK	LHEE	LTOE	RTHI	RKNE	RTIB	RANK	RHEE	RTOE	LASI	RASI	LPSI	RPSI	LTHI	LKNE	LTIB	LANK	LHEE	LTOE	RTHI	RKNE	RTIB	RANK	RHEE	RTOE
1	0.694	0.694	0.749	0.735	0.408	0.344	0.178	0.051	0.031	0.026	0.553	0.328	0.249	0.033	0.033	0.033	0.674	0.674	0.732	0.729	0.403	0.322	0.152	0.029	0.026	0.012	0.535	0.310	0.231	0.03	0.02	0.025
2	0.709	0.709	0.750	0.736	0.382	0.336	0.151	0.046	0.031	0.027	0.554	0.313	0.234	0.037	0.023	0.018	0.687	0.687	0.718	0.708	0.407	0.316	0.127	0.034	0.023	0.012	0.533	0.309	0.247	0.02	0.01	0.012
3	0.581	0.581	0.603	0.589	0.342	0.271	0.095	0.030	0.028	0.019	0.475	0.274	0.209	0.033	0.024	0.024	0.569	0.569	0.596	0.580	0.311	0.251	0.092	0.020	0.020	0.014	0.442	0.259	0.199	0.01	0.02	0.020
4	0.645	0.645	0.689	0.687	0.366	0.285	0.142	0.002	0.006	-0.006	0.483	0.297	0.238	-0.004	0.000	0.000	0.649	0.649	0.670	0.660	0.347	0.308	0.119	0.011	0.020	0.005	0.534	0.303	0.241	0.02	0.01	0.019
5	0.660	0.660	0.717	0.713	0.386	0.301	0.114	0.013	0.001	-0.003	0.482	0.304	0.240	0.016	0.006	0.006	0.645	0.645	0.713	0.704	0.374	0.312	0.113	0.011	-0.004	-0.006	0.500	0.304	0.240	0.03	-0.03	-0.003
6	0.550	0.556	0.583	0.582	0.300	0.265	0.097	0.007	0.008	-0.005	0.411	0.265	0.201	0.001	0.003	-0.012	0.553	0.553	0.587	0.580	0.317	0.247	0.101	0.011	0.000	0.000	0.422	0.262	0.212	0.01	0.01	0.005
7	0.698	0.698	0.728	0.724	0.404	0.340	0.141	0.027	0.017	0.004	0.549	0.320	0.222	0.023	0.018	0.018	0.706	0.706	0.733	0.724	0.411	0.340	0.154	0.029	0.019	0.007	0.526	0.348	0.269	0.03	0.02	0.016
8	0.772	0.772	0.797	0.787	0.435	0.348	0.168	0.032	0.021	0.003	0.565	0.375	0.287	0.018	0.015	0.015	0.784	0.784	0.812	0.802	0.457	0.382	0.172	0.026	0.015	0.006	0.590	0.376	0.238	0.03	0.01	0.008
9	0.723	0.723	0.776	0.774	0.397	0.338	0.154	0.027	0.017	0.006	0.590	0.349	0.257	0.021	0.011	0.011	0.718	0.718	0.758	0.753	0.407	0.351	0.159	0.026	0.020	0.005	0.541	0.334	0.237	0.02	0.02	0.015
10	0.651	0.651	0.689	0.687	0.360	0.307	0.111	0.028	0.016	0.009	0.492	0.308	0.231	0.018	0.010	0.010	0.637	0.637	0.671	0.673	0.355	0.300	0.141	0.014	0.009	0.005	0.445	0.309	0.255	0.01	0.01	0.006
11	0.669	0.669	0.704	0.704	0.386	0.319	0.137	0.029	0.021	0.012	0.522	0.329	0.249	0.032	0.017	0.017	0.657	0.657	0.697	0.689	0.367	0.313	0.139	0.024	0.012	0.005	0.477	0.326	0.250	0.03	0.01	0.007
12	0.766	0.766	0.813	0.811	0.441	0.366	0.153	0.020	0.017	0.010	0.569	0.353	0.265	0.022	0.020	0.020	0.777	0.777	0.810	0.802	0.448	0.346	0.141	0.023	0.014	0.010	0.490	0.352	0.264	0.03	0.01	0.006
13	0.613	0.613	0.638	0.632	0.344	0.288	0.123	0.019	0.010	0.005	0.462	0.264	0.200	0.016	0.004	0.004	0.620	0.620	0.634	0.643	0.352	0.299	0.101	0.021	0.005	0.006	0.452	0.287	0.204	0.01	0.01	0.008

3) Reliability of tempo-spatial parameters for typically developing children

Reliability of tempo-spatial parameters for typically developing children

Subject	**Session1**									**Session2**								
	Speed	Stride Width	Cycle Time	Stride Length	step Length	step Time	stance Time	swing Time	step/ Min	Speed	Stride Width	Cycle Time	Stride Length	step Length	step Time	stance Time	swing Time	step/ Min
1	1.16	0.103	0.959	1.108	0.562	0.489	0.588	0.368	122.993	1.024	0.095	1.044	1.069	0.53	0.524	0.638	0.412	114.873
2	1.429	0.096	0.807	1.66	0.589	0.418	0.485	0.333	144.017	1.325	0.101	0.831	1.49	0.556	0.417	0.493	0.341	144.421
3	1.13	0.092	0.868	1.007	0.503	0.437	0.529	0.345	138.255	1.247	0.116	0.763	0.975	0.465	0.379	0.475	0.295	159.134
4	1.022	0.1	1.042	1.07	0.537	0.532	0.641	0.413	113.678	1.118	0.103	0.956	1.064	0.514	0.474	0.581	0.376	126.644
5	1.33	0.104	0.886	1.183	0.61	0.454	0.533	0.354	134.287	1.288	0.144	0.897	1.143	0.586	0.436	0.551	0.351	137.814
6	1.256	0.098	0.82	1.03	0.535	0.401	0.503	0.317	133.749	1.225	0.076	0.853	1.068	0.526	0.429	0.518	0.34	140.281
7	1.007	0.094	1.08	1.111	0.617	0.553	0.649	0.446	108.986	0.997	0.116	1.112	1.109	0.558	0.543	0.665	0.447	110.818
8	1.214	0.112	1.012	1.224	0.599	0.506	0.617	0.394	118.89	1.214	0.112	1.012	1.224	0.599	0.506	0.617	0.394	118.89
9	1.385	0.125	0.771	1.045	0.561	0.351	0.516	0.267	132.088	1.367	0.103	0.851	1.153	0.597	0.424	0.514	0.333	141.635
10	1.325	0.093	0.873	1.146	0.571	0.436	0.526	0.349	138.09	1.43	0.106	0.776	1.041	0.604	0.414	0.495	0.328	145.589
11	1.088	0.094	0.995	1.102	0.547	0.496	0.609	0.404	121.312	1.076	0.112	1.026	1.091	0.555	0.512	0.616	0.418	117.603
12	0.967	0.095	1.147	1.112	0.55	0.577	0.679	0.473	104.136	1.066	0.11	1.106	1.178	0.57	0.551	0.671	0.429	109.238
13	1.162	0.05	0.931	1.083	0.537	0.456	0.572	0.362	120.735	1.068	0.074	0.98	1.05	0.528	0.491	0.596	0.38	122.21

4) Reliability of walking kinematic parameters for typically developing children

Reliability of walking kinematic parameters for typically developing children																														
S	**Session1**															**Session2**														
	Ankle fle/ ext	**Ankle add/ abd**	**Ankle rotation**	**Hip fle /ext**	**Hip add/ abd**	**Hip Rotation**	**Knee fle /ext**	**Knee add/ abd**	**Knee rotation**	**pelvic tilt**	**pelvic obliquity**	**pelvic rotation**	**Trunk tilt**	**Trunk obliquity**	**Trunk rotation**	**Ankle fle/ ext**	**Ankle add/a bd**	**Ankle rotation**	**Hip fle/ ext**	**Hip add/a bd**	**Hip Rotation**	**Knee fle/ ext**	**Knee add/ abd**	**Knee rotation**	**pelvic tilt**	**pelvic obliquity**	**pelvic rotation**	**Trunk tilt**	**Trunk obliquity**	**Trunk rotation**
1	19.03	20.08	9.65	49.97	12.98	16.06	69.91	14.50	14.61	3.59	10.93	18.92	3.16	8.73	17.79	26.03	23.11	13.16	47.46	9.26	11.55	68.79	25.61	13.09	2.81	11.66	17.91	2.70	6.24	19.47
2	29.77	10.78	3.24	48.10	9.05	22.59	65.48	5.37	6.43	3.12	12.97	20.19	4.64	11.11	21.29	31.60	20.70	4.05	44.15	9.89	23.28	67.36	11.86	10.42	1.84	7.76	16.80	1.59	6.26	17.09
3	21.31	18.38	8.53	48.98	12.87	11.30	58.90	20.48	11.11	5.56	10.46	22.22	5.59	8.04	22.84	21.30	11.42	5.78	50.47	10.44	14.49	69.15	6.08	14.81	4.92	9.82	18.66	5.41	5.91	19.50
4	20.70	13.65	6.00	44.36	8.92	20.16	54.83	8.50	6.24	3.32	6.41	17.39	3.10	5.41	16.61	25.14	16.33	4.62	47.92	12.46	11.37	62.05	11.19	9.07	4.11	11.48	18.69	4.93	10.84	18.71
5	25.07	21.41	6.65	57.16	10.95	18.25	64.37	10.45	11.31	3.09	12.59	17.21	3.46	7.64	18.59	32.38	30.45	11.00	42.26	10.20	16.91	55.51	10.25	29.62	4.19	9.61	20.09	3.87	3.94	21.39
6	24.70	30.38	4.70	59.17	13.66	14.05	63.87	10.87	19.45	2.63	16.34	26.43	2.86	10.03	28.79	31.17	35.16	10.57	55.62	15.18	11.94	64.57	28.43	9.88	4.45	13.59	28.33	3.35	8.49	29.31
7	25.21	16.18	11.49	43.86	11.01	9.95	59.79	21.65	7.94	5.47	12.62	28.83	6.79	9.20	29.53	28.52	29.57	6.47	44.70	13.33	12.30	63.55	15.17	15.36	7.33	13.71	26.25	7.08	8.62	26.98
8	26.52	13.19	7.45	41.39	11.60	21.83	67.71	7.45	15.36	5.99	11.56	17.66	5.58	9.93	16.55	26.52	13.19	7.45	41.39	11.60	21.83	67.71	7.45	15.36	5.99	11.56	17.66	5.58	9.93	16.55
9	15.62	12.24	3.99	36.83	7.29	5.60	65.94	8.90	10.65	3.29	6.08	17.99	2.89	3.85	18.08	25.05	13.99	5.36	42.78	11.29	14.94	70.74	7.23	11.18	3.03	10.13	20.54	2.59	8.21	20.51
10	32.13	18.95	3.96	58.44	13.86	14.60	57.50	13.79	8.66	2.51	11.75	26.32	2.84	8.95	27.06	26.17	17.53	11.72	57.17	12.97	27.56	59.75	19.87	10.25	3.61	11.15	22.26	2.61	9.84	22.40
11	33.73	19.41	4.16	45.43	10.05	7.87	68.95	9.71	20.64	3.33	11.91	18.61	3.84	7.48	19.96	35.04	24.33	4.28	43.97	11.06	12.36	69.73	14.05	21.63	3.20	10.96	15.00	3.43	8.79	14.86
12	27.73	16.50	7.03	36.67	8.46	16.27	56.92	13.50	14.57	3.01	12.25	24.23	3.82	9.93	24.67	23.38	28.34	9.29	44.08	13.26	46.26	57.35	33.22	11.67	3.25	13.63	24.38	3.31	12.26	24.29
13	38.45	18.56	11.50	59.60	19.29	33.17	68.57	16.86	5.61	3.17	16.20	22.59	4.98	16.43	22.40	28.41	20.25	14.55	58.59	17.11	44.13	62.40	26.69	12.82	2.34	17.20	23.60	3.75	16.85	23.82

5) Reliability of walking kinetic parameters for typically developing children

Reliability of walking kinetic Peaks for typically developing children

S	**Session1**									**Session2**								
	V GRF	Ankle extensor Moment	Ankle Power	Hip ext. Moment	Hip abductor Moment	Hip Power	Knee extensor. Moment	Knee abductor. Moment	Knee Power	V GRF	Ankle extensor Moment	Ankle Power	Hip extensor. Moment	Hip abductor Moment	Hip Power	Knee extensor Moment	Knee abductor. Moment	Knee Power
1	1.31	1.30	2.36	0.55	0.53	0.78	0.44	0.28	0.84	1.22	1.34	3.19	0.69	0.43	0.99	0.03	0.26	0.47
2	1.05	1.14	3.44	0.84	0.72	1.84	0.22	0.32	0.97	1.14	0.94	2.75	0.97	0.72	1.40	0.60	0.37	0.84
3	1.09	0.70	1.72	0.36	0.45	1.09	0.24	0.18	0.26	1.09	0.63	1.54	0.39	0.14	1.75	0.61	0.01	0.63
4	1.09	0.78	1.78	0.20	0.26	0.64	0.35	0.03	0.25	1.08	0.85	1.81	0.29	0.23	1.48	0.19	0.06	0.87
5	1.41	0.95	2.15	0.55	0.46	2.37	0.38	0.02	2.35	1.25	0.74	1.68	0.33	0.37	0.64	0.18	0.03	0.63
6	1.10	0.60	1.58	0.73	0.45	1.40	0.22	0.19	1.81	1.10	0.37	0.91	0.64	0.66	1.29	0.47	0.21	0.96
7	1.07	0.82	1.38	0.28	0.33	0.76	0.21	0.08	0.14	1.02	0.86	1.65	0.31	0.47	0.55	0.16	0.06	0.18
8	1.26	1.50	3.76	0.92	0.87	1.29	0.11	0.53	1.76	1.16	1.51	4.31	0.73	0.88	1.18	0.11	0.48	1.60
9	1.13	1.14	3.73	0.43	0.32	2.14	0.45	0.06	0.99	1.42	1.06	2.44	0.50	0.30	1.54	0.76	0.04	2.04
10	1.10	0.61	1.20	0.71	0.60	1.25	0.49	0.17	1.14	1.10	0.61	1.50	0.57	0.43	1.96	0.14	0.24	0.58
11	1.09	1.06	3.23	0.27	0.26	0.80	0.26	0.01	0.37	1.04	0.96	3.16	0.33	0.24	1.00	0.35	0.04	0.52
12	1.20	1.26	2.05	0.65	0.97	1.04	0.33	0.57	0.63	1.18	1.23	2.50	0.74	0.94	3.09	0.50	0.36	0.43
13	1.10	0.64	1.70	0.50	0.51	1.36	0.34	0.13	0.68	1.10	0.65	1.76	0.45	0.29	0.75	0.24	0.03	0.31