Associations between physical activity, pain, injuries and joint loading in children, and how these factors may affect recommendations regarding the type of physical activity that children should perform whilst taking environmental and personal barriers into consideration

A thesis submitted for the degree of Doctor of Philosophy

By

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THESIS ABSTRACT

Physical activity recommendations advise children to engage in weight bearing activities to optimise bone health. However, in certain populations, e.g. children with overweight and obesity, weight bearing activities may lead to increased joint loading and consequently, lower limb pain. Cycling, as a non-weight bearing activity, may generate less joint loading and potentially less pain than weight bearing activities. Understanding the interactions between joint loading, pain and activity may help to make recommendations regarding physical activity for children. However, even if cycling is favourable to weight bearing activity in terms of joint loading and pain, other barriers to participation in cycling, such as the environmental and personal factors, may exist. Therefore, the overall goal of this thesis was to investigate associations between physical activity, pain, injuries and, joint loading in children, and how these factors may affect recommendations regarding the type of physical activity that children should perform whilst taking environmental and personal barriers into consideration. The thesis used a multimethod research design with a QUAN → qual combination and a deductive theoretical drive. Findings indicated that there is no evidence that moderate physical activity and vigorous physical activity, respectively, are associated with pain and injuries in children. Findings also indicated that, at similar physiological loads, joint loading is less during cycling than during walking among children, but there is no difference in pain between walking and cycling. Lastly, barriers such as parental concerns regarding safety, limited resources, the environment including traffic and weather, and lack of infrastructure prevent children from using a bicycle to actively commute. Together, these findings provide information to support health professionals when making physical activity recommendations for children. While cycling may be more suitable than weight bearing activities for some children because of reduced joint loading, environmental and personal barriers to cycling should be considered when making recommendations.

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"If I have seen farther, it is by standing on the shoulders of giants."

(Sir Isaac Newton, 1675[6])

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BMI	Body Mass Index
MPA	Moderate Physical Activity
MVPA	Moderate to Vigorous Physical Activity
OB	Obesity
OW	Overweight
PA	Physical activity
VPA	Vigorous Physical Activity

CHAPTER 1. GENERAL INTRODUCTION

1.1 Introduction

Physical activity (PA) is an essential part of a healthy lifestyle. Current PA recommendations put an emphasis on weight bearing activities to promote an appropriate amount of joint loading leading to good bone health. However, not always are weight bearing activities advisable for example when considering overweight (OW) or obese populations where excessive joint loading may lead to pain and joint injuries. Non-weight bearing activities such as cycling can be performed at similar intensities as weight bearing activities, and therefore confer similar health benefits, while potentially having biomechanical benefits. Whilst from a physiological and biomechanical point of view cycling may be recommendable for populations at risk of pain due to excess joint loading, environmental and personal factors may prevent participation in cycling. This thesis aimed to investigate associations between PA, pain, injuries and, joint loading in children, and how these factors may affect recommendations regarding the type of PA that children should perform whilst taking environmental and personal barriers into consideration. The purpose of this general introduction is to introduce the relevant concepts of PA, OW and obesity (OB), joint loading and active commuting. This is followed by a scoping review of the relevant literature, which identifies gaps and provides rationales for the thesis' overall aim and the subsequent studies.

1.2 Definition of PA

PA is a broad concept that is defined as any bodily movement generated by skeletal muscle that results in energy expenditure (Caspersen, Powell, & Christenson, 1985). More specifically, the literature describes the term PA as a complex construct with different types and outputs (Shephard, 2003). Overall, there are three types of PA: *leisure* includes activities performed for relaxation that are practised with intrinsic motivation; *volitional* refers to activities that are executed primarily with a purpose, in an either structured or unstructured environment; and *spontaneous* activities are performed in short periods of movement that result in energy expenditure, including unintentional movements, e.g. gesticulation or fidgeting (Thomas & Nelson, 2001). PA outputs are *frequency* which is related to the number of times, or bouts, in a week that PA is performed; *duration* refers to the quantity of time spent on a type of PA; and *intensity* which refers to the difficulty of the activity. Intensity is usually categorised as light, moderate, or vigorous (Butte, Ekelund, & Westerterp, 2012; Welk, Corbin, & Dale, 2000).

PA intensity can be reported as *absolute* or *relative*. Absolute intensity means that PA is being measured using the quantity of energy required by the body per minute of activity. Relative intensity refers to the degree of exertion required by an individual to perform PA (Centers for Disease Control and Prevention, 2015). The unit used to describe absolute terms is the metabolic equivalent (MET), which considers active and resting metabolic ratios (Thomas & Nelson, 2001). The term MET is defined as a physiological standard to express energetic demand of physical activities (Ainsworth et al., 2000). Light PA is considered as <3 METs, moderate PA (MPA) is considered as 3-6 METs, and vigorous PA (VPA) is considered as >6 METs. Relative intensity can be expressed using the percentage of maximum oxygen uptake, percentage of maximum heart rate, or using a scale to rate perceived exertion (Thomas & Nelson, 2001). PA *dose* refers to the combination of intensity, frequency and duration of PA. PA dose can be described in kilocalories per day, METs per hour, kilocalories per activity or other units (Thomas & Nelson, 2001). Exercise is a type of PA to maintain or improve health (Caspersen et al., 1985). Unlike other PA, it is structured and planned and typically performed to maintain or improve physical fitness (Shephard, 2003).

1.3 How PA is measured: subjective and objective methods

PA is a dynamic component and not simple to be measured (Broderick, Ryan, Donnell, & Hussey, 2014). Taking into account that youth have not been following PA recommendations (Kalman et al., 2015), it is imperative to correctly assess PA in order to provide precise advice for this population. Essentially, PA can be measured using subjective and objective methods (Loprinzi & Cardinal, 2011). Subjective methods are usually less expensive than objective methods and are also known as self-report methods. The most frequent self-report methods used in research involving children are questionnaires and PA diaries (Biddle, Gorely, Pearson, & Bull, 2011). These instruments are generally previously validated against direct PA measures in order to avoid bias. Some advantages of using self-report methods for assessing PA in children are relatively low cost in comparison to direct methods and the possibility of identifying

PA type that participants engaged. Questionnaires allow participants to describe sedentary behaviour type that they were engaged, i.e. computer or watching television, as sedentary behaviour is generally assessed by measuring minutes or hours dedicated to screen time (Loprinzi & Cardinal, 2011). On the other hand, disadvantages of self-report methods are the fact that researchers have to rely on participants' memory to accurately report their activities over the past day or week, according to the questionnaire or diary used (Mattocks, Tilling, & Riddoch, 2008). Objective methods for assessing PA in children are advised due to their significant accuracy.

Common devices to objectively assess PA in children are accelerometers and pedometers (Mattocks et al., 2008). Accelerometry is considered more accurate than questionnaires and activity diaries as they generally rely on electro-mechanical piezoelectric sensors to detect acceleration and software to analyse participants' data (Mattocks et al., 2008). Similarly to subjective methods, objective methods for assessing PA also have to be validated against gold standard criteria for measuring energy expenditure. These gold standard criteria can be indirect calorimetry, which provides O_2 consumption as the unit of measurement, and doubly labelled water which provides CO_2 production as the unit of measurement (Welk et al., 2000). Thus, objective methods such as accelerometers can provide more accurate PA outcomes than questionnaires and activity diaries, specifically triaxial devices when compared to uniaxial accelerometers (Butte et al., 2012). Nevertheless, objective methods also present disadvantages when compared to subjective methods for assessing PA in children. Some disadvantages related to accelerometry are relatively high cost and limitation to measure water-based activities such as swimming. One advantage related to accelerometry is their efficiency when assessing PA intensities, moderate or vigorous for instance, and the opportunity to choose different epoch lengths (Mattocks et al., 2007). An epoch is a precise time interval that accelerometers use to filter digitised signals of acceleration (Trost, Mciver, & Pate, 2005). The accelerometer registers all the activity counts at the end of an epoch in its memory. Children present different PA patterns than adults as they tend to engage in different PA intensities in very short bursts (Heil, Brage, & Rothney, 2012). Therefore, to measure PA in this population with minimum bias, it is essential to choose a tool that allows the selection of different epoch lengths when analysing data (Nilsson, Ekelund, Yngve, & Söström, 2002).

1.4 PA benefits

Benefits of PA include prevention of several types of cancers (Kerr, Anderson, & Lippman, 2017), positive effects on cardiovascular health (Curtis et al., 2017; Wen et al., 2011), and better academic performance (Landry & Driscoll, 2012). The current UK PA guidelines state that children should engage in at least 60 minutes of moderate to vigorous PA (MVPA) every day (Department of Health Physical Activity Health Improvement and Protection, 2011). Specifically, all children should practice vigorous activities, along with activities that strengthen muscles and bones, at least three times per week and reduce time spent on sedentary activities, e.g. screen time (Department of Health Physical Activity Health Improvement and Protection, 2011). Following PA guidelines can protect children against conditions such as cardiovascular diseases (Andersen et al., 2006) and OW and OB (de Bourdeaudhuij et al., 2013; Katzmarzyk et al., 2015; Ramires, Dumith, & Goncalves, 2015). However, evidence shows that the majority of children and adolescents are not meeting PA recommendations (Kalman et al., 2015).

1.5 PA and joint loading

While current recommendations for PA in children focus on weight bearing activities such as walking, jumping rope and hopscotch in order to improve bone health (Department of Health Physical Activity Health Improvement and Protection, 2011), they may not be the most appropriate activities for all children (Lerner, Board, & Browning, 2016). Walking is a potentially inexpensive form of MPA that can decrease blood pressure, coronary heart disease and body mass index (BMI) (Bravata et al., 2007; Chan, Ryan, & Tudor-Locke, 2004; Lee, Rexrose, Cook, Manson, & Buring, 2001; Murtagh, Murphy, & Boone-Heinonen, 2010). However, a recent study suggested that walking duration was related to increased loading on the medial knee compartment (Lerner et al., 2016). Excessive loading in hip, knee and ankle joints and increased plantar pressures during walking (Pau, Leban, Corona, Gioi, & Nussbaum, 2016) may be related to lower-limb and foot pain (Smith, Sumar, & Dixon, 2014; Stovitz, Pardee, Vazquez, Duval, & Schwimmer, 2008), which may affect a child's quality of life due to chronic pain (Smith et al., 2014). Pain during PA may be one factor that can prevent children from achieving PA recommendations.

In particular, children who are OW or obese experience greater joint loading during walking than children with healthy weight (Browning & Kram, 2007; Dowling, Steele, & Baur, 2004; Lerner et al., 2016; Mickle, Steele, & Munro, 2006). OW and OB are defined as excess body fat that may result in impaired health (World Health Organization, 2000). The excessive accumulation of body fat can increase the risk of morbidity and all-cause mortality (Aune et al., 2016; The Global BMI Mortality Collaboration et al., 2016) including cancer (Hidayat, Du, Chen, Shi, & Shi, 2016) and cardiovascular disease (Bridger, 2009; Herouvi, Karanasios, Karayianni, & Karavanaki, 2013; Srinivasan, Bao, Wattigney, & Berenson, 1996). Thus, it is crucial to accurately measure excess weight among individuals. BMI is a frequently used method to classify thinness, OW and OB. It is calculated as the weight of a person, in kilograms, divided by their stature, in metres, to the power of two (World Health Organization, 2000). The World Health Organization (2000) BMI cut-offs for adults are: underweight < 18.5 kg/m^2; normal range 18.5-24.9 kg/m^2; OW 25-29.9 kg/m^2; and OB ≥ 30 kg/m^2. OB may be further divided into sub-categories as obese class I (30.0-34.9 kg/m^2), obese class II (35.0-39.9 kg/m^2) and obese class III (≥ 40.0 kg/m^2) (World Health Organization, 2000).

Although BMI is widely used to determine OW and OB, it is an indirect method that uses anthropometry to estimate body fat (Duren et al., 2008). BMI is therefore only a surrogate measure of excess body fat, used to identify individuals potentially at risk of comorbidity (World Health Organization, 2000). Other indirect methods also use anthropometry to identify those with excess body fat, such as abdominal circumference and skinfolds (Duren et al., 2008). Although these are recommended for use in adults to identify cardiometabolic risk factors (World Health Organization, 2008), their use in children is limited because of a lack of consensus on cut-off points for determining OW or OB.

Criterion methods of assessing a person's body fat include magnetic resonance imaging (MRI), dual-energy X-ray absorptiometry, and air displacement plethysmography, and hydrostatic weighing also known as hydrodensitometry.

However, these methods are expensive and often inaccessible. Other techniques that can be used to estimate a person’s body fat percentage are skinfold thickness and bioelectric impedance analysis. Although one of the advantages of bioelectric impedance analysis is that it can provide information on changes in lean mass and body fat over time, changes in total body weight over time can lead to errors (Wells & Fewtrell, 2005). One disadvantage of the skinfold method is the poor accuracy and precision of predicting body fat percentage from skinfold thickness when using an equation to predict body fat percentage that was not developed from a comparable population (Wells & Fewtrell, 2005). It also has poor accuracy in obese populations, likely because of the difficulty in obtaining an accurate measure of skinfold thickness if a person has excess subcutaneous fat (Wells & Fewtrell, 2005).

Pain is one factor that can prevent children from achieving current PA recommendations. Children with OB experience pain in more locations and report more lower limb pain than children with healthy weight (Tsiros et al., 2014). Evidence in the literature, also, suggests that being obese in childhood can lead children to experience back pain, injuries and fractures (Paulis, Silva, Koes, & van Middelkoop, 2014). Excess body weight, causing greater joint loading during walking (Lerner et al., 2016), may partly explain why children with OB experience a greater prevalence of musculoskeletal pain and injuries compared to children with healthy weight (Browning, 2012). The fact that there are adaptations in gait and muscle imbalances in lower limbs, can also explain reasons for children to experience lower limb pain (Shultz, D’Hondt, Fink, Lenoir, & Hills, 2014). Therefore walking, or other weight bearing activities, may not be the most acceptable form of PA to children with OW and OB. As children are failing to reach PA recommendations, actions to increase PA in this population has been requested (Wilkie et al., 2016).

It has been documented by Ericson & Nisell (1986) that cycling, a non-weight bearing activity, induces low tibiofemoral joint forces compared to other activities such as walking and stair climbing. Cycling has also been proven to be a protective factor against excess body weight (Bere, Seiler, Eikemo, Oenema, & Brug, 2011; Dudas & Crocetti, 2008), leads to good cardiorespiratory fitness (Maher, Voss, Ogunleye, Micklewright, & Sandercock, 2012; Oja et al., 2011), and increases agility, balance, and reaction response (Lirgg, Gorman, Merrie, & Hadadi, 2018; Rissel, Passmore, Mason, & Merom, 2013). Cycling is also associated with a lower risk of cancer, cardiovascular diseases and all-cause mortality (Celis-Morales et al., 2017). Cycling can be moderate or vigorous intensity, depending on the exertion dedicated to the task (U.S. Department of Health and Human Services, 2008), and therefore contributes to PA recommendations. However, despite the benefits associated with cycling, high bike ownership in England (National Travel Survey: England 2015, 2016), and enjoyment of cycling among children (Chandler et al., 2015), participation in cycling is low (Voss & Sandercock, 2010). Evidence shows that inappropriate infrastructure, e.g. a lack of bike paths (Carver et al., 2005; Carver, Timperio, & Crawford, 2015; de Vries, Hopman-Rock, Bakker, Hirasing, & van Mechelen, 2010) and high parental concern (Kerr et al., 2006) are some of the barriers that children face regarding cycling to school.

1.6 Definition of active commuting

The way children commute to and from school has been described in the literature as passive or active commuting (Larouche et al., 2014; Davison et al., 2008; Lee, Orenstein, & Richardson, 2008 Johnston & Moreno, 2012). Active commuting is defined as the usage of non-motorised modes of transport that one uses to travel from home to work or school, i.e. bicycling or walking from home to school (Lee et al., 2008). Active commuting among children in England is low, with the most recent evidence available indicating that between 2% and 8% of children cycle to school (Christie et al., 2011; Voss & Sandercock, 2010). The number of children who actively commute appears to have declined over the past decades. In the United States, for instance, 42% of children walked or cycled to school in 1969 compared to only 16.2% in 2001 (Ham, Martin, & Kohl, 2008). This is concerning as active commuting presents an opportunity for children to participate in MVPA. There is evidence in the literature that active commuting, that is walking or cycling, can increase daily MVPA (Yang, Panter, Griffin, & Ogilvie, 2012) and physical wellbeing in adults (Humphreys, Goodman, & Ogilvie, 2013). Davison et al. (2008) outlined that children who walk or cycle to school not only displayed higher levels of PA than their peers who did not engage in active commuting but also presented better cardiovascular fitness (Chillón et al., 2010).

Evidence suggests that active commuting, also known as active transport or transportation, should be encouraged in order to increase current low levels of PA in children (Wilkie et al., 2016). Encouraging active commuting by bicycle among children may be a particular way to increase participation in cycling (Lee et al., 2008). In the United Kingdom, the National Cycle Proficiency Scheme training, currently known as *Bikeability* (Goodman, van Sluijs, & Ogilvie, 2015), has been introduced to support bicycling and safe attitudes while bicycling in children (Goodman, van Sluijs, & Ogilvie, 2016; Teyhan, Cornish, Boyd, Sissons Joshi, & Macleod, 2016). *Bikeability* is a cycling training programme, which consists of levels 1, 2 and 3. In the *Bikeability* programme, trainees can become proficient cyclists by learning necessary skills to perform safe travels on busy roads (Department for Transport, 2018). The *Bikeability* scheme aims to improve skills of trainees (Goodman et al., 2016). However, wider factors may influence whether or not a child cycles to school, such as the availability of bike lanes, time, and convenience (Kerr et al., 2006a; Silva, Vasques, Martins, Williams, & Lopes, 2011). Thus, an understanding of barriers that children face related to active commuting on a bicycle is needed (Carver et al., 2015).

1.7 Conclusion

In conclusion, children are advised to engage in daily MVPA (Department of Health Physical Activity Health Improvement and Protection, 2011). While PA has many health benefits, joint loading during some types of PA may cause pain, which may act as a barrier to PA (Boutevillain, Dupeyron, Rouch, Richard, & Coudeyre, 2017; Pellegrini, Ledford, Chang, & Cameron, 2018). In particular, pain may be more prevalent during PA among children with OW and OB because excess body weight increases joint loading during weight bearing activities (Lerner et al., 2016). Cycling is a type of MVPA that may result in less joint loading than weight bearing activities such as walking. Taking into account that children should follow PA recommendations, cycling may represent a feasible activity for children who experience pain as a result of joint loading to participate in. However, even if cycling is associated with lower joint loading and pain than weight bearing activities, participation in cycling in England is low. Active commuting to school may be a way to increase participation in PA, but reasons why children are not cycling to school need further exploration in order to identify ways to increase participation. Thus, the overall goal of this thesis was to investigate associations between PA, pain, injuries and, joint loading in children, and how these factors may affect recommendations regarding the type of PA that children should perform whilst taking environmental and personal barriers into consideration.

To provide a foundation for the rationale of the thesis' overall aim and its individual experimental chapters, a scoping review of the literature is conducted in order to address the following questions:

1. What is the association between PA, pain and injury in children?
2. What is the association between joint loading, PA and pain in children?
3. Does joint loading differ between cycling and other types of activities in children?
4. What is the feasibility of cycling as a form of active commuting among children?

CHAPTER 2. LITERATURE REVIEW

The aims of the literature review were to answer: What is the association between PA, pain and injury in children? What is the association between joint loading, PA and pain in children? Does joint loading differ between cycling and other types of activities? What is the feasibility of cycling as a form of active commuting among children?

2.1 Methodology

2.1.1 Eligibility criteria

Original articles that addressed at least one of the aims of the literature review were included. Participants were children and adolescents, aged 0 to 18 years, with no physical impairments or disabilities. Studies that assessed habitual physical activities only were included. There are a vast number of studies in the literature investigating specific sports, pain and injuries in children. More specifically, many studies have investigated the relationship or prevalence of pain and injuries in young athletes. This literature review did not include these studies as it was not aiming to investigate whether or not injuries and pain were related to specific sports. Narrative reviews, case studies, and commentaries were also excluded. Articles that were published in languages other than English were excluded.

2.1.2 Search strategy

In order to develop the search strategy of the present scoping review, assistance from a librarian was sought at Brunel University London. Several meetings between the PhD researcher and the librarian, specialised in literature review, were held. The librarian recommended that two major electronic databases, i.e. PubMed and SPORTDiscus, should be searched. The search strategy was developed by identifying search terms relating to the review questions and performing preliminary searches to identify terms used in titles and abstracts of relevant studies. Further meetings with a librarian were held in order to use appropriate truncation and wildcard symbols for each database. Search terms included words relating to children (e.g. children, youth, toddler, infant), PA (e.g. PA, activity, exercise, accelerometer), pain (e.g. pain), injuries (e.g. injury, fracture), joint loading (e.g. joint load, load, weight bearing, ground reaction forces, kinetics), and active commuting (e.g. commuting, active commuting, cycling).

The search strategy used in the present review of the literature can be found in appendix I. Separate searches were conducted for each review question.

After exploring both electronic libraries, a large number of articles were retrieved i.e. approximately 70,000 titles. The search strategy was limited to articles that were published from January 1st 2000 up to July 31st 2018 to include only the most recent evidence. These criteria were set up using advanced search functions on these electronic libraries.

The management of retrieved articles was carried out using the software Mendeley Desktop (Elsevier, Amsterdam, Netherlands) version 1.19.4. After setting up advanced searches on the electronic libraries for each question, results from searches performed on PubMed and SPORTDiscus were imported to Mendeley Desktop and duplications were removed. Search results were organised according to the review question. Titles and abstracts of identified studies for each question were screened for eligibility against the inclusion and exclusion criteria previously described, i.e. results for question number one were all allocated to folder number one and screened before moving on to results for question number two. Potentially eligible articles were tagged using the favourite function of the software. The full article was retrieved for studies that met the inclusion criteria and for studies where it was not possible to include or exclude based on the title and abstract. The reference lists of included studies were also screened for additional articles.

2.1.3 Data extraction and analysis

Data on participants, such as age and sex, methods employed by the study, and main results were extracted from included articles. A narrative synthesis of studies is provided. The appropriate CASP (Critical Appraisal Skills Programme) checklist (e.g. for observational study designs) and AXIS tool (Appraisal tool for Cross-Sectional Studies) (Downes, Brennan, Williams, & Dean, 2016) were used to appraise the methodological quality of each included study. The CASP checklists (for case-control studies, cohort studies, qualitative studies and systematic reviews) can be found in appendix II and the AXIS tool (for cross-sectional studies) can be found in appendix III.

2.2 Results

Table 2.1 provides a summary of records found in each database before and after removal of duplications. The search initially identified 22,680 records in PubMed and SPORTDiscus. A total of 21,656 records were screened by titles and abstracts after removal of duplicate records. We identified twenty studies related to question number one: *What is the association between PA, pain and injury in children?* As these studies addressed the association between PA and pain or PA and injury, we report the results of these studies separately (i.e., the association between PA and pain, and the association between PA and injury, respectively). Two studies related to question number two: *What is the association between joint loading, PA and pain in children?* No study was retrieved in relation to question number three: *Does joint loading differ between cycling and other types of activities in children?* Five studies related to question number four: *What is the feasibility of cycling as a form of active commuting among children?*

Table 2.1 Search results retrieved from each database.

Database	Search date	Database date range	Number of records	Number of records after removal of duplicates
PubMed	July 31st, 2018	January 1st 2000 up to July 31st 2018	17 950	17 744
SPORTDiscus	July 31st, 2018	January 1st 2000 up to July 31st 2018	4 730	3 912

Overall, twenty-seven studies were included in the present literature review. Figure 2.1 presents a flow chart of the systematic search used in this chapter.

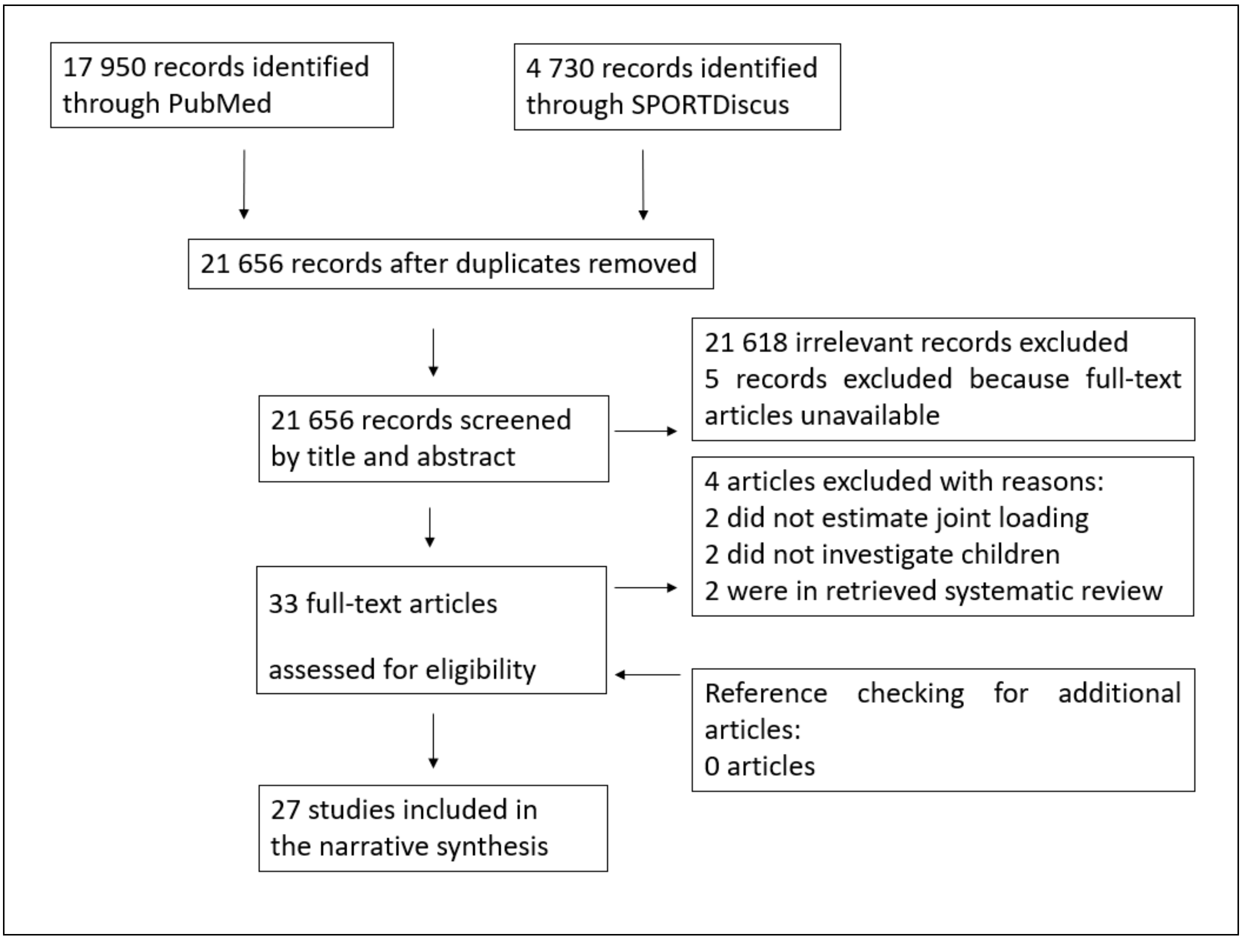


Figure 2.1 Flow diagram.

2.2.1 Question 1a. Association between PA and pain

Overall eleven studies examined the association between PA and pain in children. One systematic review examined the association between PA and neck and low back pain only and included 17 studies published up to June 2009 (Sitthipornvorakul, Janwantanakul, Purepong, Pensri, & van der Beek, 2011). Ten additional studies that were not included in the systematic review were identified. Nine studies had cross-sectional designs (Coleman, Straker, & Ciccarelli, 2009; Martínez-López et al., 2015; Papadopoulou, Malliou, Kofotolis, Emmanouilidou, & Kellis, 2014; Pereira, Castro, Bertoncello, Damiao, & Walsh, 2013; Silva, Sa-Couto, Queiros, Neto, & Rocha, 2017; Skoffer & Foldspang, 2008; Sollerhed, Andersson, & Ejlertsson, 2013; Swain et al., 2016; Watson et al., 2003) and one study had a prospective cohort design (Aartun, Hartvigsen, Boyle, & Hestbaek, 2016).

2.2.1.1 Findings from the systematic review

Although the systematic review (Sitthipornvorakul et al., 2011) identified 17 studies, the authors only included thirteen articles in their review. The authors reported that four articles were excluded from the review due to low quality (Sitthipornvorakul et al., 2011). A standardized checklist with seventeen questions was used to assess methodological quality of studies retrieved in their systematic search. Whilst the name of the tool used for quality appraisal was not reported in their systematic review, the authors reported that the checklist was used in previous systematic reviews on musculoskeletal symptoms (Chen, Liu, Cook, Bass, & Lo, 2009; Hoogendoorn et al., 2000; van der Windt et al., 2000). Ten studies had cross-sectional designs and three studies were cohort studies. The authors included studies where the study sample was representative of the general population. While they do not define "general population", they state they exclude studies of athletes, patients and pregnant women. Of the included studies, participants in three studies were described as "general population", participants in nine studies were described as "school children", and participants in one study were described as "working population". The authors did not describe more data regarding participants (Sitthipornvorakul et al., 2011) or specify the age range of participants. Although the review included studies of children and adults, it was included in the present literature review as the majority of the included studies were of children (Sitthipornvorakul et al., 2011). The weight status of participants was also not described in the systematic review. The systematic review found no evidence of an association between PA and neck pain in school children. There was inconsistent evidence for the association between PA and low back pain in school children. The authors reported that there was heterogeneity between methods used in studies, as studies used different methods or instruments to assess PA and pain. Effect sizes were not stated in the systematic review.

Importantly, the majority of included studies assessed PA using a self-report method. Only one study objectively measured PA (Wedderkopp, Kjaer, Hestbaek, Korsholm, & Leboeuf-Yde, 2009) and another study used both subjective and objective methods for assessing PA (Wedderkopp, Leboeuf-Yde, Bo Andersen, Froberg, & Steen Hansen, 2003). Wedderkopp et al. (2009) conducted a prospective cohort study, involving Danish children aged nine years that were followed-up until the age of 12 years, to examine the association between pain and objectively measured PA. The study assessed back pain at baseline and follow-up by asking children whether they experienced low back, mid back, or neck pain over the past month. PA was objectively assessed using MTI-accelerometers and presented as counts per minute. PA was categorised into low-, moderate- and high-activity levels. Results of the study showed that participants who engaged in the lowest tertile of high PA and counts per minute were more likely to experience any type of back pain compared to participants who engaged in the highest tertile of high PA (OR: 6.8; 95% CI: 1.4 to 32.5). Limitations related to the study conducted by Wedderkopp et al. (2009) are limited regions to report pain, i.e. they specifically examined back pain only, the intensity of pain was not considered, and the authors did not include children's body weight status in their analysis.

Wedderkopp et al. (2003) conducted a cross-sectional study involving Danish boys and girls aged 8 to 16 years to examine the association between pain and both self-report and objective PA. Pain was assessed using a questionnaire and the recall period was one month. Participants were asked to report whether or not they experienced back pain in the following regions: low back, mid back or neck. PA was presented as counts per minute using accelerometers and as a sum of scores from the questionnaire leading to level 1 (least active) to level 4 (most active). The authors reported that objectively measured PA was not associated with back pain, low back pain or mid back pain, as odds ratios were 1 in all occasions. Limitations on the investigation conducted by Wedderkopp et al. (2003) are the limitation of pain sites, i.e. the investigation specifically examined back and neck pain only, the intensity of pain was not considered and the authors did not examine whether or not the association between PA and pain differs according to body weight status of children.

Five other studies included in the systematic review conducted by Sitthipornvorakul et al. (2011), subjectively measured PA to assess the relationship between PA and neck pain in school children. Four studies had cross-sectional designs (Auvinen, Tammelin, Taimela, Zitting, & Karppinen, 2007; Diepenmaat, van der Wal, de Vet, & Hirasing, 2006; Kujala, Taimela, & Viljanen, 1999; Østerås, Ljunggren, Gould, Wærsted, & Bo Veiersted, 2006) and one had a prospective cohort (Mikkelsson et al., 2006). All studies used self-reported methods to measure pain. Four studies reported no statistically significant relationship between self-reported PA and neck pain (Auvinen et al., 2007; Diepenmaat et al., 2006; Kujala et al., 1999; Mikkelsson et al., 2006). One study reported no statistically significant relationship between self-reported PA and neck or upper back pain (Østerås et al., 2006).

There are limitations in the systematic review conducted by Sitthipornvorakul et al. (2011). The review included “high” quality studies only, as determined by the authors using a tool that is not widely used to assess study quality. The search strategy retrieved publications in English language only. In summary, the review found no evidence of an association between PA and neck pain and mixed evidence for the association between PA and back pain. However, the majority of included studies used self-report measures of PA. The two studies that objectively measured PA found different results; one found no association between PA and neck or back pain (Wedderkopp et al. 2003) and one found an association between elevated PA engagement and low incidence of low and mid-back pain in children (Wedderkopp et al., 2009).

2.2.1.2 Findings from additional studies

Of the remaining ten studies that examined the association between PA and pain, nine of them measured PA using subjective methods and one assessed PA using an objective measure.

Studies using subjective measures of PA

Of the studies that used subjective measures of PA, two studies specifically measured the intensity of PA (Silva et al., 2017; Swain et al., 2016). Silva et al. (2017) also assessed time in sedentary activities using a self-report measure. Four studies measured self-reported participation in physical activities but not PA intensity (Papadopoulou et al., 2014; Pereira et al., 2013; Sollerhed et al., 2013;), one study measured self-reported participation in sport and sedentary activities (Watson et al., 2003), and three studies measured self-reported participation in sedentary activities and PA (Coleman et al., 2009; Martínez-López et al., 2015; Skoffer & Foldspang, 2008).

Silva et al. (2017) conducted a cross-sectional study involving 969 boys and girls aged 13 to 15 years. An adapted version of the *Nordic Musculoskeletal Questionnaire* was used to assess pain. The outcome of this questionnaire was pain in the neck, shoulders, elbows, wrists/hands, mid back, lumbar region, hips, knees and ankles/feet over the past seven days. When experiencing pain students were asked to report pain on a scale ranging from 0 to 10 to indicate pain intensity in each body site described above. Time engaged in sedentary behaviour, i.e. time spent using a computer, time in MPA, and time in VPA were assessed using a questionnaire. The authors reported that more time spent in MPA was significantly associated with a higher probability of reporting pain on neck (OR: 1.06; 95% CI: 1.02 to 1.12), shoulders (OR: 1.06; 95% CI: 1.01 to 1.10), low back (OR: 1.05; 95% CI: 1.01 to 1.09), wrists (OR: 1.09; 95% CI: 1.03 to 1.14), hips (OR: 1.06; 95% CI: 1.01 to 1.11), knees (OR: 1.04; 95% CI: 1.01 to 1.19) and ankles/feet (OR: 1.08; 95% CI: 1.03 to 1.13). More time spent in VPA was significantly associated with a higher probability of reporting pain on shoulders (OR: 1.04; 95% CI: 1.01 to 1.09), mid back (OR: 1.06; 95% CI: 1.02 to 1.11), knees (OR: 1.08; 95% CI1.03 to 1.13) and ankles/feet (OR: 1.05; 95% CI: 1.01 to 1.10). Although the authors included body weight status in their analysis, the study did not examine whether or not the association between PA and pain differed according to weight status (OW/OB).

Swain et al. (2016) conducted a cross-sectional study involving 242,103 boys and girls aged 11 to 15 years. Participants were asked if they experienced the following in the past 6 months: 1) no pain; 2) headache only; 3) stomach-ache only; 4) backache only;

5) headache and stomach-ache; 6) headache and backache; 7) stomach-ache and backache; and 8) headache, stomach ache, and backache. For each type of pain, respondents were required to specify the frequency of pain in the last six months on a five-point scale. Pain frequency was then dichotomized as rarely or never/ at least every month. No details regarding the intensity of pain were available in this study. The frequency of MVPA was measured using the question: "Over the past seven days (week), on how many days were you physically active for a total of at least 60 min per day?". The authors found that reduced participation in MVPA was associated with presence of back pain, headache and stomach-ache in girls and also associated with combined headache and stomach-ache or headache in boys. The association and effect size of pain with reduced PA varied according to the type of pain experienced, sex and age. In girls, aged 11 years, the probability of meeting the MVPA recommendations according to the World Health Organisation was reduced when they experienced a combination of stomach-ache and backache (OR: 0.79; 95% CI: 0.68 to 0.91). In boys, aged 11 years, the probability of meeting the MVPA recommendations was reduced when they experienced a combination of headache and stomach-ache (OR: 0.78; 95% CI: 0.73 to 0.84). A combination of headache, stomach-ache and backache reduced chances of girls aged 11 years meeting MPVA recommendations (OR: 0.91; 95% CI: 0.84 to 0.99). Similarly, in boys, the same combination of pain sites reduced chances of them meeting MVPA recommendations (OR: 0.94; 95% CI: 0.87 to 1.02). The authors did not examine whether or not the association between PA and pain differed according to weight status.

Papadopoulou et al. (2014) conducted a cross-sectional study involving 614 boys and girls aged 15 to 16 years. Pain was reported by participants using the following question "During the past four weeks, have you had pain while carrying your backpack?". In case they answered yes, students were asked to specify regions that they experienced pain. Pain intensity was not measured in this study. Children were requested to recall the number of hours that they had systematically engaged in PA per week, including PA type and sports performance, over the past 12 months. The authors compared hours of PA per week that boys and girls with and without pain engaged. The authors reported that more hours engaged in PA per week was associated with lower pain incidents ($p < 0.05$). Upper and lower back pain were more prevalent in boys who engaged in significantly fewer hours of PA than their peers who did not report pain ($p < 0.05$). The authors did not examine whether or not the association between these variables differ according to weight status.

Sollerhed et al. (2013) conducted a cross-sectional study involving 206 boys and girls aged 8 to 12 years. Pain was reported using a questionnaire. Pain outcome was recurrent pain region or type, i.e. headache, abdominal pain, back pain, feel irritated, feel sick, feel tired, feel sad, poor appetite and sleeping problems and frequency (yes = every day or every week. no = never to once a month). Pain intensity was not measured. PA was assessed using several questions asking them the number of hours that they engaged in PA in their leisure time, physical education classes in school and whether they were member of sports clubs. The authors reported that low PA was associated with recurrent pain. Children who were less physically active reported more pain symptoms than their active peers (OR: 2.1; 95% CI: 1.1 to 3.9; $p < 0.05$). The association between PA and pain was not examined according to weight status in this study.

Watson et al. (2003) conducted a cross-sectional study involving 1,376 boys and girls aged 11 to 14 years. Two methods were used to assess low back pain: a direct question “In the past month have you had low back pain which lasted for one day or longer?” and “In the past month have you experienced pain in the shaded area which lasted for one day or longer?”. To fulfil criteria for low back pain, participants had to respond positively to both questions. Pain intensity was not measured in this study. Sedentary activities, i.e. time spent watching television and using computer, and sport participation were also assessed using questions. The authors reported that spending more than 4 hours/week practising sports was associated with risk of low back pain when compared to practising 121 minutes or less per week (OR: 1.4; 95% CI: 1.02 to 1.9). Sedentary activities were not associated with risk of low back pain. A limitation to this investigation was the limited site for reporting pain, i.e. low back pain only. The authors did not examine whether or not the association between PA and low back pain differs according to weight status.

Pereira et al. (2013) conducted a cross-sectional study involving 262 boys and girls aged 6 to 12 years. A questionnaire was developed for the study so that children were able to report the presence of pain, pain location and PA. Pain outcome was the presence or absence of pain in each of the seven following options: arms, spine, shoulders, hands, legs, feet and others (in the presence of the latter option, the site was described). Pain intensity was not measured. PA was reported using a question asking whether or not children engaged in physical exercise outside school. The authors reported that musculoskeletal pain was associated with physical exercise outside school ($p = 0.05$). One of the limitations of this study was that the authors did not examine PA intensity and pain intensity. Although the authors have included body weight status in their analysis, their analysis did not assess whether or not the association between PA and low back pain changed according to weight status (OW/OB).

Coleman et al. (2009) conducted a cross-sectional study to examine the association between sedentary activities and pain in 88 boys and girls aged 11 to 16.9 years. Body weight was not assessed. Overall pain was reported using the question "In the last month, how often did you feel any soreness, pain or discomfort?". Pain outcome was the frequency of pain and intensity ranging from 0 to 10. Results from their investigation documented that sedentary behaviour was associated with pain frequency. Participants of the study reported to researchers that the reason for their musculoskeletal discomfort was due to constant engagement in sedentary activities such as watching television, reading, writing and using a computer. The effect sizes were not reported in this study. As weight was not assessed, the analysis did not assess whether or not the association between PA and low back pain changed according to weight status (OW/OB).

Martínez-López et al. (2015) conducted a cross-sectional study involving 2,293 boys and girls aged 12 to 16 years. A single item was used to assess pain: ''In the last six months, how often have you felt the following: headache, stomach-ache, backache, feeling low, irritability or bad temper, feeling nervous, difficulties getting to sleep, feeling dizzy?''. Results from their investigation documented that self-reported sedentary behaviour using a questionnaire was associated with pain. The authors reported that boys who use computers for long periods reported more pain than their peers who never use computers (OR: 1.18; 95% CI: 1.006 to 1.383; $p = 0.042$). Low weekly PA was related to a greater risk of suffering pain among boys sometimes vs never (OR: 1.30; 95% CI: 1.015 to 1.672; $p = 0.038$) but not among girls. Limitations to this study are self-reported weight, height, PA, sedentary lifestyle, self-perceived health, pain and well-being. This study did not examine whether or not the association between these variables differed according to weight status as BMI was used for adjusting analysis only.

Skoffer & Foldspang (2008) conducted a cross-sectional study involving 546 boys and girls aged 15 to 16 years. A questionnaire was used for participants to report low back pain episodes over the past three months. The intensity and duration of low back pain were also assessed with a questionnaire. Sedentary behaviour, measured using a questionnaire, was associated with low back pain. The authors reported that low back pain was associated with time spent watching television or time spent doing homework (OR: 1.07; 95% CI: 1.01 to 1.1; $p = 0.014$). One limitation in this investigation was the limited region to report pain, i.e. low back pain only. The authors did not include body weight status in their analysis and did not examine whether or not the association differed according to weight status.

Studies using objective measures of PA

The present systematic search retrieved only one study that examined the association between objectively measured PA and sedentary behaviour, and pain in children (Aartun et al., 2016).

Aartun et al. (2016) conducted a school-based cohort study involving 906 (n = 625 at follow-up) boys and girls aged 11-13 years. PA was assessed at baseline using *Actigraph GT3X* triaxial activity monitors and the outcomes were sedentary behaviour, MVPA and VPA. An individual electronic questionnaire was used to assess neck, mid back and low back pain at baseline and at a follow-up two years later. Participants were asked 'Have you ever had neck pain?' with the response options 'often', 'sometimes', 'once or twice' and 'never'. Pain outcome was the number of spinal pain sites and frequency of spinal pain. The authors found no association between different levels of PA or sedentary behaviour and spinal pain cross-sectionally. The effect sizes were not stated. No association was found between different levels of PA or sedentary behaviour and spinal pain longitudinally (OR: 0.94; 95% CI: 0.84 to 1.04). A limitation of this study was that the authors did not examine whether or not the association between PA and pain differed according to children's body weight status. Additionally, the questionnaire used to recall pain focused only on neck, mid back and low back pain.

2.2.1.3 Quality appraisal

The internal and external validity of cross-sectional studies was assessed with the AXIS tool (Downes et al., 2016) and the results of the analysis can be seen in table 2.2. With regards to the introduction, out of nine cross-sectional studies, nine studies presented clear aims (Coleman et al., 2009; Martínez-López et al., 2015; Papadopoulou et al., 2014; Pereira et al., 2013; Silva et al., 2017; Skoffer & Foldspang, 2008; Sollerhed et al., 2013; Swain et al., 2016; Watson et al., 2003). Question number two of the AXIS tool asks whether or not the study had an appropriate design for its aims. All studies investigating the relationship between PA and pain had appropriate designs. A cross-sectional design was an appropriate design to assess associations between PA and pain. However, a cohort study design would be more appropriate for determining the direction of association as the exposure is measured before the outcome. In cross-sectional studies, any associations observed may be a result of pain causing a change in PA or participation in PA causing a change in pain. With regards to methods, all cross-sectional studies justified their sample sizes and all of them also clearly defined their reference population. Question number five of the AXIS tool asks whether or not the sample frame was taken from an appropriate population base in order to represent the population under investigation. All cross-sectional studies used appropriate population bases to represent the population under investigation as the studies aimed to investigate issues among children and their participants were children. Three studies had selection processes that were likely to select subjects/participants that were representative of the target/reference population under investigation. These studies followed a process of random sampling (Martínez-López et al., 2015), or used a multinational survey system to collect samples that were nationally representative (Swain et al., 2016) or used samples from rural and urban communities from different counties (Watson et al., 2003). The question number seven of the AXIS tool asks whether or not studies took measures to address and categorise participants that did not respond to questionnaires or instruments used in their research, i.e. compare their data with participants included in their final analyses. No cross-sectional study presented measures to address and categorise non-responders. All studies measured appropriate explanatory and outcome variables to address the aims of the study. Two studies did not measure the explanatory and outcome variables using instruments that had been previously trialled, piloted or published (Pereira et al., 2013; Skoffer & Foldspang, 2008). As mentioned above, the majority of studies used self-report measures to assess PA and/or sedentary behaviour, which may have been inaccurate. One study did not clearly present what was used to determine statistical significance (Coleman et al., 2009). One study did not sufficiently describe its methods (including statistical methods) to enable them to be repeated as it did not clearly present what was used to determine statistical significance (Coleman et al., 2009). With regards to results, three studies did not adequately describe the basic data (Coleman et al., 2009; Pereira et al., 2013; Swain et al., 2016). In three studies it was not possible to tell whether or not participants' response rate raised concerns about non-response bias as they did not supply information on non-response (Martínez-López et al., 2015; Pereira et al., 2013; Sollerhed et al., 2013). Only one study described information about non-responders (Papadopoulou et al., 2014; Skoffer & Foldspang, 2008). Question number fifteen of the tool asks whether or not the results of studies were internally consistent. Results from all studies were internally consistent results. All studies reported results of analyses that were previously described in methods. With regards to discussion, all studies had discussions and conclusions justified by the results. Two studies did not discuss limitations of the study (Skoffer & Foldspang, 2008; Watson et al., 2003). In three studies it was not possible to tell whether or not any funding sources or conflicts of interest may have affected the interpretation of results by the authors (Papadopoulou et al., 2014; Pereira et al., 2013; Sollerhed et al., 2013). All studies obtained ethical approval or consent of participants.

Table 2.2 Internal and external validity of cross-sectional studies according to the AXIS tool.

Quality item	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cross-sectional study																				
Coleman et al. (2009)	Y	Y	Y	Y	Y	N	N	Y	Y	N	N	N	N	N	Y	Y	Y	Y	N	Y
Martínez-López et al. (2015)	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	?	N	Y	Y	Y	Y	N	Y
Papadopoulou et al. (2014)	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	?	Y
Pereira et al. (2013)	Y	Y	Y	Y	Y	N	N	Y	N	Y	Y	N	?	N	Y	Y	Y	Y	?	Y
Silva et al. (2017)	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	N	Y
Skoffer and Foldspang (2008)	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y	N	Y	Y	Y	Y	N	N	Y
Sollerhed et al. (2013)	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	?	N	Y	Y	Y	Y	?	Y
Swain et al. (2016)	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	N	Y
Watson et al. (2003)	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	N	Y	Y	Y	N	N	Y
Lowry et al. (2007)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	?	Y
Moustaki et al. (2005)	Y	Y	Y	Y	Y	N	N	Y	N	N	N	N	?	N	Y	Y	Y	Y	?	?
Sundblad et al. (2005)	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	N	?	N	Y	Y	Y	Y	?	Y
Lerner et al. (2016)	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	-	Y	Y	Y	Y	N	Y
Hansen et al. (2005)	Y	Y	Y	Y	Y	Y	N	Y	N	N	Y	N	?	N	Y	Y	Y	Y	?	Y
Kerr et al. (2006)	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	N	?	N	Y	Y	Y	Y	N	Y

Y = Yes. N = No. ? = Do not know. AXIS = Appraisal tool for Cross-Sectional Studies

The internal and external validity of cohort studies was assessed with a CASP tool. This paragraph will describe only the quality appraisal of the study conducted by Aartun et al. (2016). The quality appraisal of the remaining cohort studies is described in other sections of the literature review, i.e. section 2.2.2 and section 2.2.3. With regards to the quality appraisal of the cohort study according to the CASP, the study conducted by Aartun et al. (2016) clearly addressed a focused issue. The cohort was recruited in an acceptable way. The exposure was accurately measured to minimise bias. The outcome was accurately measured to minimise bias. The authors identified all important confounding factors. The authors also took into account confounding factors in the design and/or analysis. At follow-up, more than 20% of the sample did not complete the questionnaire. Therefore the follow-up of subjects was not complete enough. The follow-up performed in the study conducted by Aartun et al. (2016) occurred after two years, which may not be not long enough period to observe long term associations between PA and spinal pain. Results show no association between different levels of PA and spinal pain cross-sectionally, but the effect sizes were not stated in the study. Nevertheless, according to question number eleven of the CASP, the results of the study fit with other available evidence in the literature. Results from the quality appraisal of the cohort study according to the CASP can be seen in table 2.3.

Table 2.3 Internal and external validity of all cohort studies included in the present literature review according to CASP.

Quality item	1	2	3	4	5a	5b	6a	6b	9	10	11
Cohort study											
Aartun et al. (2016)	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y
Bloemers et al. (2012)	Y	Y	Y	N	N	N	Y	N	Y	Y	Y
Clark et al. (2008)	Y	Y	N	Y	Y	Y	Y	N	Y	Y	Y
Fritz et al. (2016)	Y	Y	N	N	N	Y	Y	Y	Y	Y	Y
Nauta et al. (2017)	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y
Riddiford-Harland et al. (2016)	Y	Y	Y	Y	Y	N	N	N	Y	Y	Y
Spinks et al. (2006)	Y	Y	N	Y	N	Y	N	N	Y	Y	Y

Y = Yes. N = No. ? = Can't tell. Questions 7, 8 and 12 are descriptives and are not included in the table.

With regards to the quality appraisal of the systematic review according to the CASP tool, the study conducted by Sitthipornvorakul et al. (2011) addressed a clear and focused question. Although the authors have looked up for the right type of papers, the systematic review did not define an age and only included studies that were published in English. All the important, relevant studies were included. The authors have verified the quality of included studies. The results of the review were not combined in a meta-analysis. The results cannot be applied to the local population even though important outcomes were considered as the study did not specify an age range for participants included and also performed a search that included adults, i.e. not only children. Question number ten of the CASP tool asks whether or not the benefits of the review were worth the harm and costs. The benefits of the review were worth the harms and costs as it systematically reviewed a field that had not been investigated before. Results from the quality appraisal of the systematic review according to the CASP can be seen in table 2.4.

Table 2.4 Internal and external validity of systematic review according to CASP.

Quality item	1	2	3	4	5	8	9	10
Systematic review								
Sitthipornvorakul et al. (2011)	Y	Y	Y	Y	N	N	N	Y

Y = Yes. N = No. ? = Can't tell. Questions 6 and 7 are descriptives and are not included in the table.

2.2.1.4 Summary

A summary of findings from the systematic search on PA and pain can be seen in figure 2.2 and table 2.5. Results from studies that have examined the relationship between PA and pain in children are heterogeneous. Whilst some studies have reported that high levels of PA were associated with pain in children (Pereira et al., 2013; Silva et al., 2017; Watson et al., 2003), there were studies reporting that low PA levels were associated with pain (Papadopoulou et al., 2014; Sollerhed et al., 2013; Swain et al., 2016). Some studies have documented that sedentary behaviour is associated with pain in children (Coleman et al., 2009; Martínez-López et al., 2015; Skoffer & Foldspang, 2008). Two studies, one of them being a systematic review reported no association between PA and pain (Aartun et al., 2016; Sitthipornvorakul et al., 2011). One study found that PA intensity was associated with pain in children (Silva et al., 2017). Most studies in this area measured types of PA or sedentary behaviour using subjective methods and questionnaires with limited regions for reporting pain in children. Although some studies reported they were measuring PA, they were measuring sedentary behaviour, i.e. time spent with television or using a computer. Only three studies have measured PA intensity; two using a subjective measure (Silva et al., 2017; Swain et al., 2016) and one using an objective measure (Aartun et al., 2016).

Aartun et al. (2016) found no association between different levels of objectively measured PA or sedentary behaviour and spinal pain cross-sectionally or longitudinally. Silva et al. (2017) found that more time spent in self-reported MPA was associated with a higher probability of reporting pain on neck, shoulders, low back, wrists, hips, knees and ankles/feet. The authors also reported that more time in self-reported VPA was associated with pain on shoulders, mid back, knees and ankles/feet. Swain et al. (2016) found that those with pain were less likely to participate in MVPA. However, the association between pain and PA varied according to the type of pain experienced, sex and age. These studies did not measure body weight status and used questionnaires for reporting pain with limited body regions, e.g. frequency of headache, stomach-ache, and backache only. Therefore, based on the findings of this search it is not possible to answer unequivocally whether or not PA is related to pain in children. Further, it is not possible to answer whether or not the association between PA and pain differs according to weight status.

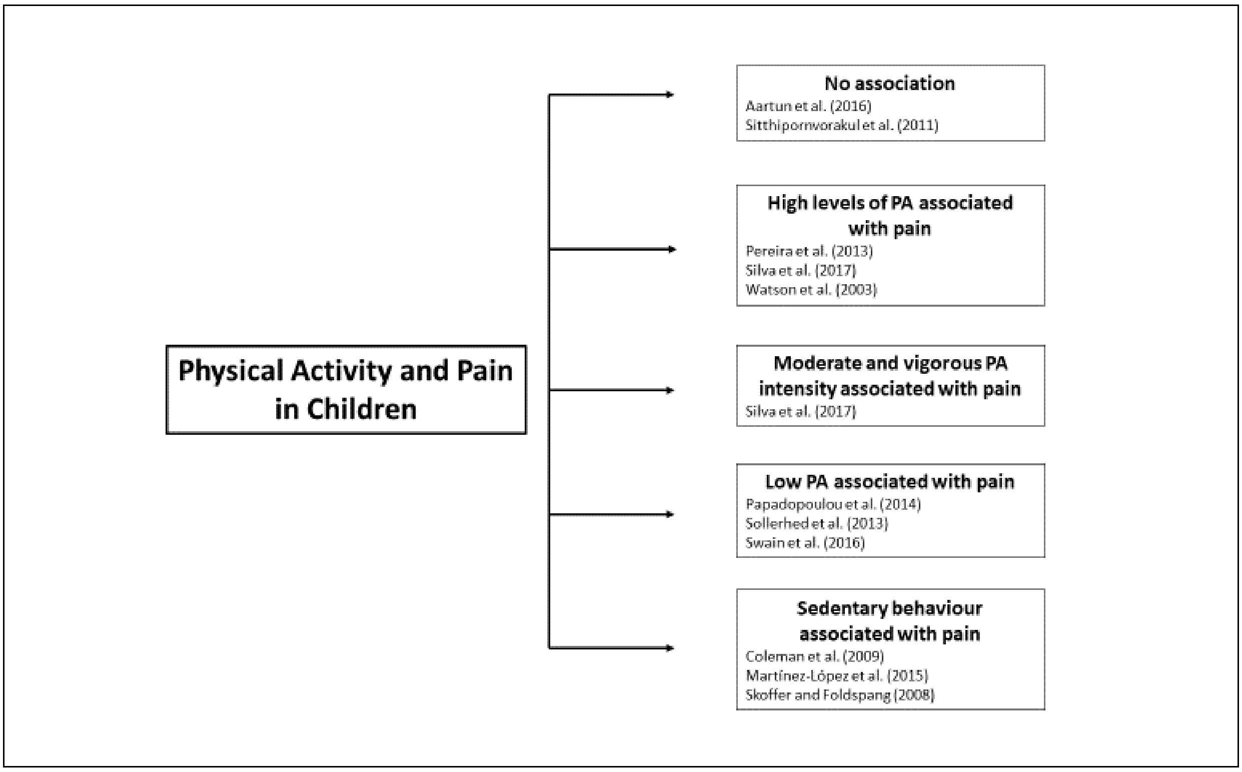


Figure 2.2 Diagram presenting the main findings from studies investigating whether PA is associated with pain in children.

Table 2.5 Summary of studies investigating the association between PA and pain in children.

Reference	Country	Study design	Sample size	Description of participants	Summary of results
Aartun et al. (2016)	Denmark	School-based prospective cohort	Baseline (n = 906) Follow-up (n = 625)	Male (53.1%) Aged 11-13 years	No association found between different levels of PA and spinal pain cross-sectionally (effect size not stated). No association found between different levels of PA and spinal pain longitudinally (OR: 0.94; 95% CI: 0.84 to 1.04).
Coleman et al. (2009)	Australia	Cross-sectional	88	Male (50%) Aged 11-16.9 years	Participants related their musculoskeletal discomfort to bad posture and performing specific activities for long periods. Effect size no stated.
Martínez-López et al. (2015)	Spain	Cross-sectional	2 293	Male (49.8%). Aged 12-16 years	Low weekly PA was related to a greater risk of suffering pain among boys sometimes, but not among girls (vs never; OR: 1.30; 95% CI: 1.015 to 1.672; P = 0.038). Boys who use computer for long periods reported more pain (vs never; OR: 1.18; 95% CI: 1.006 to 1.383; P = 0.042).
Papadopoulou et al. (2014)	Greece	Cross-sectional	614	Male (74.7%) Aged 6-14 years	Body pain was reported by more than half of students carrying school bags (64.2%). Girls reported pain more frequently than boys (x^2 = 18.743; P < 0.05). Higher PA was associated with lower pain incidents (P < 0.05). Upper and lower back pain were more prevalent in boys who engaged in significantly fewer hours of PA than their peers who did not report pain (P < 0.05).

Pereira et al. (2013)	Brazil	Cross-sectional	262	Male (47.7%) Aged 6-12 years	Musculoskeletal pain was associated with physical exercise outside school ($P = 0.05$). No association between BMI and presence of pain.
Silva et al. (2017)	Portugal	Cross-sectional	969	Male (52.7%) Aged 13-15 years	More time spent in MPA was significantly associated with a higher probability of reporting pain in all body regions except the mid back over the past seven days. The percentage increases between 6 to 8% ($P < 0.05$). More time spent in VPA was significantly associated with a higher Probability of reporting pain on shoulders (OR: 1.04; 95% CI: 1.01 to 1.09), mid back (OR: 1.06; 95% CI: 1.02 to 1.11), knees (OR: 1.08; 95% CI1.03 to 1.13) and ankles/feet (OR: 1.05; 95% CI: 1.01 to 1.10).
Sitthipornvorakul et al. (2011)	Thailand	Systematic review	13 studies	School children General population	Robust evidence for no association between PA and neck pain in school children. Inconsistent evidence for the association of PA and low back pain in school children. The effects of physical on activity neck and low back pain are too heterogeneous. Effect size not stated.
Skoffer and Foldspang (2008)	Denmark	Cross-sectional	546	Male (53.3%) Aged 15-16 years	Low back pain was associated with physical inactivity, e.g. time spent watching TV or time spent doing homework (OR: 1.07; 95% CI: 1.01 to 1.1; $P = 0.014$).

Sollerhed et al. (2013)	Sweden	Cross-sectional	206	Male (55.3%) Aged 8-12 years	Low PA was associated with recurrent pain. Children who were less physically active reported more pain symptoms than their active peers (OR: 2.1; 95% CI: 1.1 to 3.9; $P < 0.05$).
Swain et al. (2016)	North America and Europe	Cross-sectional	242 103	Aged 11-15 years	Reduced PA was associated with presence of pain. The association and effect size of pain with reduced PA varies according to the type of pain experienced, sex and age.
Watson et al. (2003)	England	Cross-sectional	1 376	Male (46.1%). Aged 11-14 years	Spending more than 4 hours/week practising sports was associated with risk of low back pain (OR: 1.4; 95% CI: 1.02 to 1.9).

2.2.2 Question 1b. Association between PA and injury

Overall nine studies examined the association between PA and injury. Four studies had a prospective cohort design (Bloemers et al., 2012; Clark, Ness, & Tobias, 2008; Nauta, Jespersen, Verhagen, van Mechelen, & Wedderkopp, 2017; Spinks, McClure, Bain, & Macpherson, 2006). Three studies had cross-sectional designs (Lowry et al., 2007; Moustaki, Pitsos, Dalamaga, Dessypris, & Petridou, 2005; Sundblad et al., 2005). One study involved a population-based case control (Ma & Jones, 2003) and one study was a prospective controlled intervention (Fritz et al., 2016).

2.2.2.1 Association between subjectively measured PA and injuries

Of the nine studies retrieved in the present systematic search, eight of them measured PA using subjective methods. One study subjectively assessed PA intensity (Lowry et al., 2007). Seven studies did not assess PA intensity (Bloemers et al., 2012; Clark et al., 2008; Fritz et al., 2016; Ma & Jones, 2003; Moustaki et al., 2005; Spinks et al., 2006; Sundblad et al., 2005). One study investigated the relationship between sedentary behaviour and pain (Ma & Jones, 2003).

Lowry et al. (2007) conducted a cross-sectional study involving 28,815 students that were enrolled in 9th to 12th grades. Injury was assessed using a questionnaire. The following question was used to assess injury: “During the past 30 days, did you see a doctor or nurse for an injury that happened while exercising or playing sports?” The injury outcome was the prevalence of injury related to PA. The authors found that high frequency in MPA was associated with decreased odds (OR: 0.55; 95% CI: 0.33 to 0.92) of PA injury among OW boys (BMI ≥ 95th percentile) and with greater odds (OR: 1.30; 95% CI: 1.09 to 1.56) of PA injury among normal and underweight boys (BMI < 85th percentile). Medium (OR: 1.35; 95% CI: 1.01 to 1.81) and high (OR: 1.52; 95% CI: 1.12 to 2.04) frequency of VPA were associated with injuries among girls. A limitation of this study was that PA was self-reported. The period to recall injury was limited to 30 days. The incidence of injuries was limited to the context of exercise and sports practice only.

Bloemers et al. (2012) conducted a prospective cohort study involving 995 boys and girls aged 9 to 12 years. Injury was assessed using a questionnaire. In case children experienced an injury, a PE teacher was responsible for providing an injury registration form to the child to complete within seven days of the injury occurrence with assistance from a PE teacher. Injury outcome was the number of injuries that children sustained. PA exposure among children was registered using baseline and follow-up questionnaires. The questionnaires had standardised questions regarding children's weekly frequency and duration in PA. PA exposure was further classified in quartiles. The authors found that children who were most active presented the lowest risk for injury (HR: 0.03; 95% CI: 0.01 to 0.07). Although BMI was calculated and stratified into quartiles in this study, the authors did not examine whether or not the association between PA and injury differed according to body weight status of children.

Clark et al. (2008) conducted a prospective cohort study involving 2,692 boys and girls, from birth to 11 years old. Injury was assessed using a questionnaire with a recall period of approximately 12 and 24 months. Children who reported sustaining a fracture were requested to answer a further questionnaire where researchers collected more information about the injury. Injury outcome was the presence or absence of reported fracture over the 2-year time period as a binary outcome. According to the authors, PA data were collected using self-completion questionnaires at two different ages: 4.5 and nine years. Children had the chance to report time per week that they spent watching television and also time spent outdoors in winter and summer. The authors found that VPA was an independent risk factor for injuries in childhood. Children who reported daily or higher frequency of VPA presented double fracture risk compared to children who reported less than four weekly episodes of VPA (OR: 2.06; 95% CI: 1.21 to 1.76). One of the limitations of this study is the partial loss of the cohort due to missing data. Although BMI was calculated in this study, the authors did not examine whether or not the association differed according to body weight status.

Fritz et al. (2016) conducted a prospective controlled intervention involving 3,534 boys and girls aged 6 to 8 years. Injury incidence was identified by examining a local radiographic database that included data from all healthcare clinics in the region where the study took place. Injury outcome was the number of fractures including the type and region of the injury. The authors found that participation in a PA intervention programme annually decreased fractures ($r = -0.79$; $p = 0.04$). PA reduced the incidence rate ratio by nearly fifty percent during the seventh year (IRR: 0.52 95% CI: 0.27 to 1.01). A limitation of this study was that the authors did not register body regions that fractures occurred and neither for how long these fractures have lasted. Another limitation is that the research did not identify the type of non-organised activities participants were engaged. The authors did not assess body weight status and whether or not the association between PA and injury have differed according to body weight status of children.

Moustaki et al. (2005) conducted a cross-sectional study involving 2,167 boys and girls aged 0 to 14 years. Injury data were retrieved from a surveillance system database from a research centre over a period lasting three years. Injury outcome was the incidence, per 1000 children-year, of non-motor-vehicle knee injuries requiring hospital contact. The authors found that serious knee injuries were associated with unorganised sports practice (OR: 2.10; 95% CI: 1.05 to 4.22; $p = 0.03$). The authors did not examine whether or not the associations differ according to body weight status of children and that PA intensity was not assessed.

Spinks et al. (2006) conducted a prospective cohort study involving 744 boys and girls aged 4 to 12 years. Injury occurrence over the past 12 months, including injury location and circumstances in which it occurred, was registered using a questionnaire. Injury outcome was the number of injuries in three categories: all injuries, school injuries and non-school injuries. PA was reported using a 7-day activity diary. Parents were requested to report their child's PA, including where it was practised and details about the PA, during the whole day. Parents did not have to report in the diary the time that their children were at school. The authors found no evidence of differences in injury incidence between participation in organised or non-organised activities. Limitations to this study are that the authors did not examine whether or not the associations differ according to body weight status and that PA intensity was not assessed. Additionally, PA was reported by parents using a 7-day diary.

Sundblad et al. (2005) conducted a cross-sectional study involving 1,975 boys and girls aged 9, 12 and 15 years. Injury over the past 10 to 14 weeks, and the setting in which the injury occurred, i.e. physical education, break or leisure time, was reported using a questionnaire. Most of the injuries reported by students took place during unorganised activities while in leisure time, being 29% of injured participants. During a recall period of 10 to 14 weeks, 25% of injuries occurred during physical education classes. The effect sizes, comparing the number of injuries occurring in each setting, were not reported by the authors. Limitations to this study are that the authors did not examine whether or not the associations differ according to body weight status and that PA intensity was not assessed.

Lastly, Ma & Jones (2003) conducted a population-based case control study involving 642 boys and girls aged 9 to 16 years. Injury was assessed using a questionnaire. The outcome was different fracture types (upper arm, wrist and forearm and hand). PA, including sedentary behaviour, was assessed using a questionnaire. The authors found that days engaged in light PA participation was associated with a lower fracture risk (OR: 0.8; 95% CI: 0.7 to 1.0). Sports engagement was associated with increased hand (OR: 1.5; 95% CI: 1.1 to 2.0) and upper arm (OR: 29.8; 95% CI: 1.7 to 535) fracture risk only among boys. Sports engagement was associated with reduced wrist and forearm fracture risk only among girls (OR: 0.5; 95% CI: 0.3 to 0.9). Sedentary behaviour was related to increased risk of fracture. Specifically, the amount of time spent with television, computer and watching videos was positively associated with forearm and wrist fracture risk (OR: 1.6, 95% CI: 1.1 to 2.2). A limitation to this study is that the authors used a questionnaire with limited regions for reporting injury, e.g. hand, wrist and forearm and upper arm only.

2.2.2.2 Association between objectively measured PA and injuries

The present systematic search retrieved one study that objectively measured PA including PA intensity. Nauta et al. (2017) conducted a prospective cohort study involving 1,048 boys and girls aged 6 to 12 years. Upper extremity injuries were recorded by parents using an online short message service (SMS). Injury outcome was the incidence, type, location and circumstance of the injury, i.e. collision with a person, object or fall, etc. PA was assessed using accelerometers and the outcome was minutes spent in MVPA and sedentary time. The authors found that MVPA and sedentary behaviour were not predictors of acute upper extremity injury risk. A limitation of this study was that the authors examined the association between MVPA and injury, and not separate associations between moderate and vigorous intensities of PA and injury. Children may be more likely to experience injury during VPA. Also, injuries were not recorded during the 6-week summer holidays. The use of an online short message service to record injuries in real-time, however, is a strength of the study. Finally, the study did not assess whether the relationship between PA and injury was different in healthy weight and OW children.

2.2.2.3 Quality appraisal

Table 2.2 shows the quality appraisal of three cross-sectional studies examining the association between PA and injury. With regards to the introduction, all studies presented clear aims (Lowry et al., 2007; Moustaki et al., 2005; Sundblad et al., 2005). Question number two of the AXIS tool asks whether or not the study had an appropriate design for its aim. All studies investigating the relationship between PA and injury had appropriate designs. A cross-sectional design was an appropriate design to assess associations between PA and injury. However, a cohort study design would have provided more information regarding the direction of association as the exposure is measured before the outcome. With regards to methods, all cross-sectional studies justified their sample sizes and all of them also clearly defined their reference population. All studies took their sample frame from an appropriate population base so that it closely represented the target/reference population under investigation. One study had selection processes that were likely to select subjects/participants that were representative of the target/reference population under investigation (Lowry et al., 2007). One cross-sectional study presented measures to address and categorise non-responders (Lowry et al., 2007). All studies measured appropriate explanatory and outcome variables for the aims of the study. One study did not measure both PA and injury using an instrument that had been previously trialled, piloted or published (Moustaki et al., 2005). One study did not clearly present what was used to determine statistical significance and/or precision estimate (Moustaki et al., 2005). One study did not sufficiently describe their methods (including statistical methods) to enable them to be repeated (Moustaki et al., 2005). With regards to results, all studies did not adequately describe the basic data. In all studies, it was not possible to tell whether or not participants' response rates raise concerns about non-response bias as they did not supply information on non-response. No cross-sectional study described information about non-responders. Question number fifteen of the AXIS tool asks whether or not the results of studies were internally consistent. Results from all studies were internally consistent. All studies reported results of analyses that were previously described in methods. With regards to discussion, all studies had discussions and conclusions justified by the results. All studies discussed their limitations. In all studies, it was not possible to tell whether or not any funding sources or conflicts of interest may have affected the interpretation of results by the authors. In one study it was not possible to tell whether or not the protocol included ethical approval attainment or consent of participants (Moustaki et al., 2005).

Table 2.3 shows the quality appraisal of the cohort studies on question number two of the present review. All cohort studies clearly addressed a focused issue (Bloemers et al., 2012; Clark et al., 2008; Fritz et al., 2016; Nauta et al., 2017; Spinks et al., 2006). All cohort studies recruited participants in an acceptable way. In two cohort studies, exposures were accurately measured to minimise bias (Bloemers et al., 2012; Nauta et al., 2017) as the other studies relied on subjective methods. Three studies accurately measured the outcome to minimise bias (Clark et al., 2008; Nauta et al., 2017; Spinks et al., 2006). Three studies took into account confounding factors in the design and/or analysis (Clark et al., 2008; Fritz et al., 2016; Spinks et al., 2006). Four studies presented a complete follow up of subjects (Bloemers et al., 2012; Clark et al., 2008; Fritz et al., 2016; Nauta et al., 2017). Two studies presented appropriate follow ups of subjects as these studies presented long follow-ups to detect changes in variables such as 2.5 years (Nauta et al., 2017) and seven years (Fritz et al., 2016).

Table 2.6 shows the quality appraisal of the case-control study conducted by Ma & Jones (2003). This paragraph will describe the quality appraisal of the study conducted by Ma & Jones (2003). The quality appraisal of the case-control study conducted by Ducheyne, De Bourdeaudhuij, Lenoir, & Cardon (2013) is described in section 2.2.4. The study clearly addressed a focused issue. However, the study did not adopt an appropriate method to answer their question as PA was retrospectively assessed using a questionnaire. The authors adopted inclusion and exclusion criteria to selected potential participant and controls were randomly selected. Thus, they were recruited and selected in an acceptable way. However, the exposure was not accurately measured to minimise bias as the authors rely on subjective methods to assess PA. The authors did not take into account potential confounding factors in their analysis.

Table 2.6 Internal and external validity of case-control studies according to CASP.

Quality item	1	2	3	4	5	6a	6b	9	10	11
Case control study										
Ducheyne et al. (2013)	Y	Y	Y	Y	Y	?	N	Y	Y	Y
Ma and Jones (2003)	Y	N	Y	Y	N	?	N	Y	Y	Y

Y = Yes. N = No. ? = Can't tell. Questions 7 and 8 are descriptives and are not included in the table.

2.2.2.4 Summary

A summary of findings from the systematic search on PA and injuries can be seen in figure 2.3 and table 2.7. Studies in this field present conflicting results. Although studies have reported that self-reported PA engagement was associated with low injury risk (Bloemers et al., 2012; Fritz et al., 2016), these studies did not examine PA intensity. Other studies have reported that self-reported engagement in unorganised activities and sports were associated with increased risk of injuries in children (Moustaki et al., 2005; Spinks et al., 2006; Sundblad et al., 2005). One study reported that self-reported participation in sedentary behaviour was associated with increased fracture risk, whereas self-reported participation in light PA was associated with decreased fracture risk (Ma & Jones, 2003). Two other studies that subjectively measured PA reported that VPA was associated with increased risk of injuries (Clark et al., 2008; Lowry et al., 2007). Finally, only one study objectively measured PA and reported that MPA was not a predictor of upper extremity injuries in children (Nauta et al., 2017). However, this study focused on upper extremity injuries only. No study has investigated whether or not objectively measured PA intensity is associated with overall injuries in children and whether or not this relationship differs according to body weight status of children.

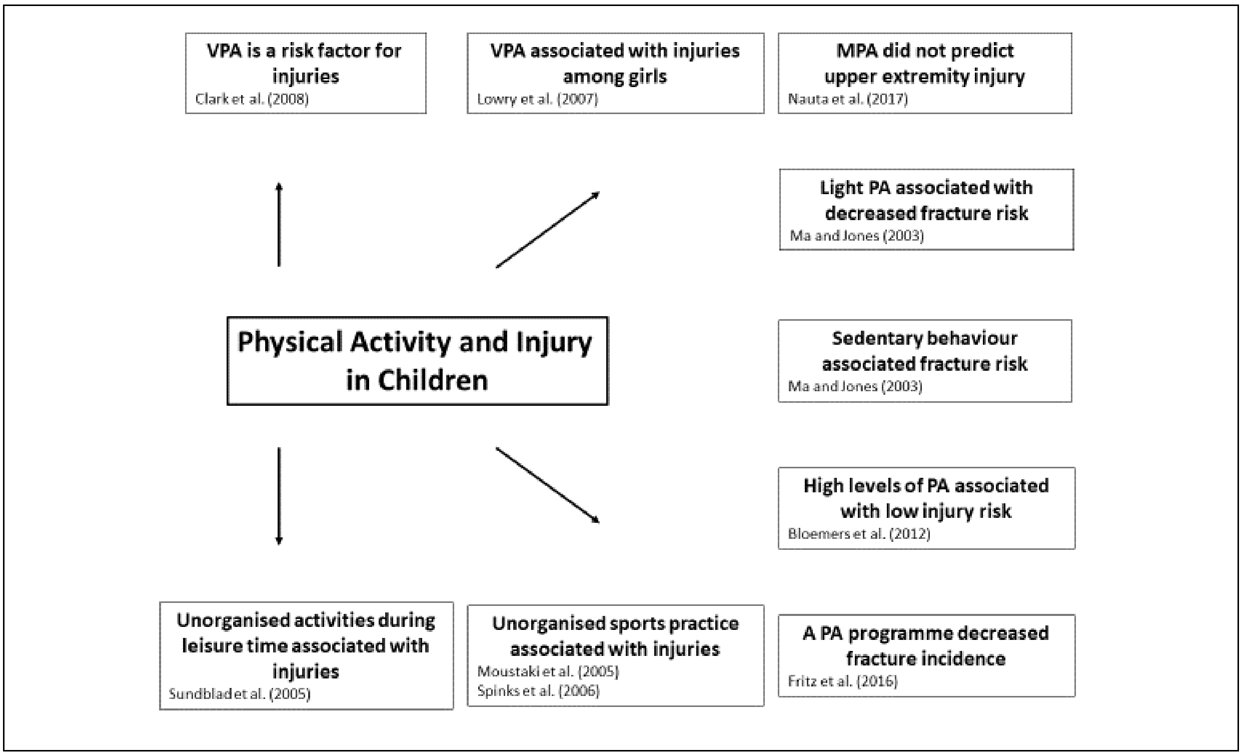


Figure 2.3 Diagram presenting the main findings from studies investigating whether PA is associated with injuries in children.

Table 2.7 Summary of studies investigating the association between PA and injuries in children.

Reference	Country	Study design	Sample size	Description of participants	Summary of results
Bloemers et al. (2012)	Netherlands	Prospective cohort study	995	Male (49.5%) Aged 9-12 years	Children who were most active presented the lowest risk for injury (HR: 0.03; 95% CI: 0.01 to 0.07).
Clark et al. (2008)	England	Prospective cohort study	2 692	Male (47.4%) From birth to 11 years old	VPA is an independent risk factor for injuries in childhood. Children who reported daily or higher frequency of VPA presented double fracture risk compared to children who reported less than four weekly episodes of VPA (OR: 2.06; 95% CI: 1.21 to 1.76).
Fritz et al. (2016)	Sweden	Prospective controlled intervention	3 534	Aged 6-8 years. 7-year follow-up	A PA intervention programme annually decreased fractures (*r* = −0.79; P = 0.04). PA reduced the incidence rate ratio in nearly fifty percent during the seventh year (IRR: 0.52 95% CI: 0.27 to 1.01). PA generated gains in total spine areal bone mineral density (mean group difference: 0.03; 95% CI: 0.00 to 0.05; P = 0.006).
Lowry et al. (2007)	United States	Cross-sectional	28 815	Grade: 9th to 12th	High frequency in MPA was associated with decreased odds (OR: 0.55; 95% CI: 0.33 to 0.92) of PA injury among OW males (BMI ≥ 95th percentile) and with greater odds (OR: 1.30; 95% CI: 1.09 to 1.56) of PA injury among normal and underweight males (BMI < 85th percentile). Medium (OR: 1.35; 95% CI: 1.01 to 1.81) and high (OR: 1.52; 95% CI: 1.12 to 2.04) frequency of VPA were associated with injuries among females.

Ma and Jones (2003)	Australia	Population-based case control study	642	Male (70%) Aged 9-16 years	Days engaged in light PA participation decreased fracture risk (OR: 0.8; 95% CI: 0.7 to 1.0). The amount of time spent with television, computer and watching videos was positively associated with forearm and wrist fracture risk (OR: 1.6, 95% CI: 1.1 to 2.2). Sports engagement increased hand (OR: 1.5; 95% CI: 1.1 to 2.0) and upper arm (OR: 29.8; 95% CI: 1.7 to 535) risk only among boys whilst diminished wrist and forearm fracture risk only among girls (OR: 0.5; 95% CI: 0.3 to 0.9).
Moustaki et al. (2005)	Greece	Cross-sectional	2 167	Male (66.7%) Aged 0-14 years	Serious knee injuries are associated with unorganised sports practice (OR: 2.10; 95% CI: 1.05 to 4.22; P = 0.03). It is more likely to occur in older children aged 10 to 14 years (OR: 2.50; 95% CI: 1.74 to3.57; P = 0.0001), during winter season (OR: 2.37; 95% CI: 1.53 to 3.68; P = 0.0001) and among girls than in boys (OR: 1.31; 95% CI: 1.00 to 1.74; P = 0.05).
Nauta et al. (2017)	Denmark	Prospective cohort study	1 048	Aged 6-12 years. 2-5-year follow-up	MVPA was not a predictor of acute upper extremity injury risk. The odds of having upper extremity injuries was greater among older children (HR: 1.84; 95% CI: 1.10 to 3.09) and girls (HR: 1.40; 95% CI: 0.97 to 2.04) when compared to boys.

Spinks et al. (2006)	Australia	Prospective cohort study	744	Male (54.7%) Aged 4-12 years	Boys sustained a higher frequency of injuries than girls when practising organised and non-organised activities and require medical attention more than girls (RR: 1.89; 95% CI: 1.20 to 2.96). Serious injuries were more common among boys than in girls (RR: 2.16; 95% CI: 1.41 to 3.32). Injury incidence in the school setting had a positive trend with age. Children aged 10 to 12 years sustained more serious injuries than their young peers (RR: 2.38; 95% CI: 1.32 to 4.30).
Sundblad et al. (2005)	Sweden	Cross-sectional	1 975	Grade: 3, 6 and 9. Aged, 12 and 15 years	Girls sustained injuries during physical education classes nearly twice more often than boys (P = 0.004). Most of the injuries reported by students took place during unorganized activities while in leisure time specifically for children in third grade when compared to other grades (P = 0.007). During a recall period of 10 to 14 weeks, 25% of injuries occurred during physical education classes. Effect sizes not stated.

2.2.3 Question 2. Association between joint loading, PA and pain in children

Overall two studies that examined the association between joint loading and PA in children were identified. No study examined the association between joint loading and pain in children Lerner, Board, & Browning (2016) conducted a cross-sectional study involving 20 boys and girls aged 8 to 12 years. Participants were requested to walk on an instrumented treadmill for 20 minutes at a pace of 1.0 metre/second. The authors found that PA duration, walking, influenced loading in knees of children. At the beginning of the walking trial, total loading through the knees of children was 63% and 85%, in healthy weight and obese children respectively. At the end of the trial, these values increased to 72% and 90%, in healthy weight and obese children respectively. Joint loading during PA was 1.78 times higher among children with OB compared to children with healthy weight. Increases in tibiofemoral loading during walking in participants with OB may increase the risk of knee pain and pathology. However, the authors did not assess if an increase in joint loading during walking was associated with lower limb pain. Further, the authors did not compare joint loading during walking to joint loading during a non-weight bearing activity.

Riddiford-Harland et al. (2016) conducted a descriptive study involving 34 boys and girls aged 8.5 years old. Participants had to be OW or obese, according to the International Obesity Task Force cut-offs (Cole, Bellizzi, Flegal, & Dietz, 2000), in order to participate in their study. Children were randomized into three groups: 1) a *child-centred PA programme*, 2) another group that was a combination of the *child-centred PA* and *parent-centred dietary modification programme*, and the last group 3) included a *parent-centred dietary modification programme*. The PA programme consisted of weight bearing activities such as jumping, running, leaping and hoping. At baseline and after six months, the authors measured dynamic plantar pressure distributions underneath each child’s feet while they walked at a prearranged pace across a calibrated emed® AT-4 pressure system. Habitual PA was assessed using accelerometers. Results were divided and presented as two groups: children from both groups that engaged in the weight bearing PA programme and children who were not assigned to a group with PA tasks. No significant differences were found in body weight from children of both groups. After six months, the authors found that a weight bearing PA programme did not alter the magnitude of peak plantar pressure distributions generated during the walking assessment. However, significant increases in time-pressure integrals were found for children who engaged in the weight bearing PA programme. Increases occurred under the lateral forefoot (p = 0.036), middle (p = 0.036), medial (p = 0.002) and lateral midfoot (p = 0.036) after the six-month programme. Increases in high plantar pressure and pressure-time integrals in children mean that they are exposed to a higher risk of discomfort or pain. These are factors that can prevent children from enjoying PA. One limitation related to this study was that the acute effect of PA on joint loading was not assessed. Further, the impact of the weight bearing PA programme on joint loading was not compared to the impact of a non-weight bearing PA programme.

2.2.3.1 Quality appraisal

Tables 2.2 shows the quality appraisal for the cross-sectional study conducted by Lerner et al. (2016). With regards to the introduction, the study presented clear aims. The study presented an appropriate design for the stated aim. With regards to methods, the study justified its sample size and also clearly defined its reference population. The study had a selection process that was likely to select participants that were representative of the target/reference population under investigation as participants were recruited from elementary schools and from a medical centre. This procedure allowed the inclusion of children with healthy weight and OB in the study. The question number seven of the AXIS tool asks whether or not the study took measures to address and categorise participants that did not respond to questionnaires or instruments used in their research, i.e. to compare their data with participants included in their final analyses. Lerner et al. (2016) did not present measures to address and categorise non-responders. The study measured appropriate explanatory and outcome variables for the aims of the study using instruments that had been previously trialled, piloted or published. The study clearly presented what was used to determine statistical significance and/or precision estimate. The study sufficiently described their methods (including statistical methods) to enable them to be repeated. With regards to results, the study adequately describes the basic data. It was not possible to tell whether or not participants' response rate raise concerns about non-response bias. Question number fifteen of the tool asks whether or not the results of studies were internally consistent. Results from the study were internally consistent results. The study reported results of analyses that were previously described in methods. With regards to discussion, the study had discussions and conclusions justified by the results. The study discussed its limitations. There were no funding sources or conflicts of interest that may have affected the interpretation of results by the authors. The study obtained ethical approval and consent from participants.

Table 2.3 shows the quality appraisal of the study by Riddiford-Harland et al. (2016). The cohort study clearly addressed a focused issue. The cohort study was recruited in an acceptable way. The exposure was accurately measured to minimise bias. Although Riddiford-Harland et al. (2016) used objective methods to measure dynamic plantar pressure distributions and PA in children, the study did not accurately measure the outcome to minimise bias. The follow-up assessment of variables took place three months after the end of a 10-week PA programme used in the study. It is possible that a 3-month gap can bias effects of the PA programme conducted in the study. The study did not identify all important confounding factors. The study did not take into account confounding factors in the design and/or analysis. The study presented a complete follow up of subjects. The study presented an appropriate follow up of subjects.

2.2.3.2 Summary

A summary of findings from the systematic search on the association between joint loading, PA and pain in children can be seen in figure 2.4 and table 2.8. Two studies examined the association between joint loading and PA in children. Of the studies retrieved, one reported that time spent in PA, specifically walking, was associated with increases in joint loading in children (Lerner et al., 2016) and another study found no modifications in the magnitude of peak plantar pressure distributions after children taking part in a PA programme. Increases in high plantar pressure and pressure-time integrals in children mean that they are exposed to a higher risk of discomfort or pain. These are factors that can prevent children from enjoying PA. None of the studies retrieved in the present systematic search assessed whether or not the type of PA, specifically weight bearing vs non-weight bearing, was related to joint loading. Lastly, no study examined whether or not joint loading was associated with pain in children.

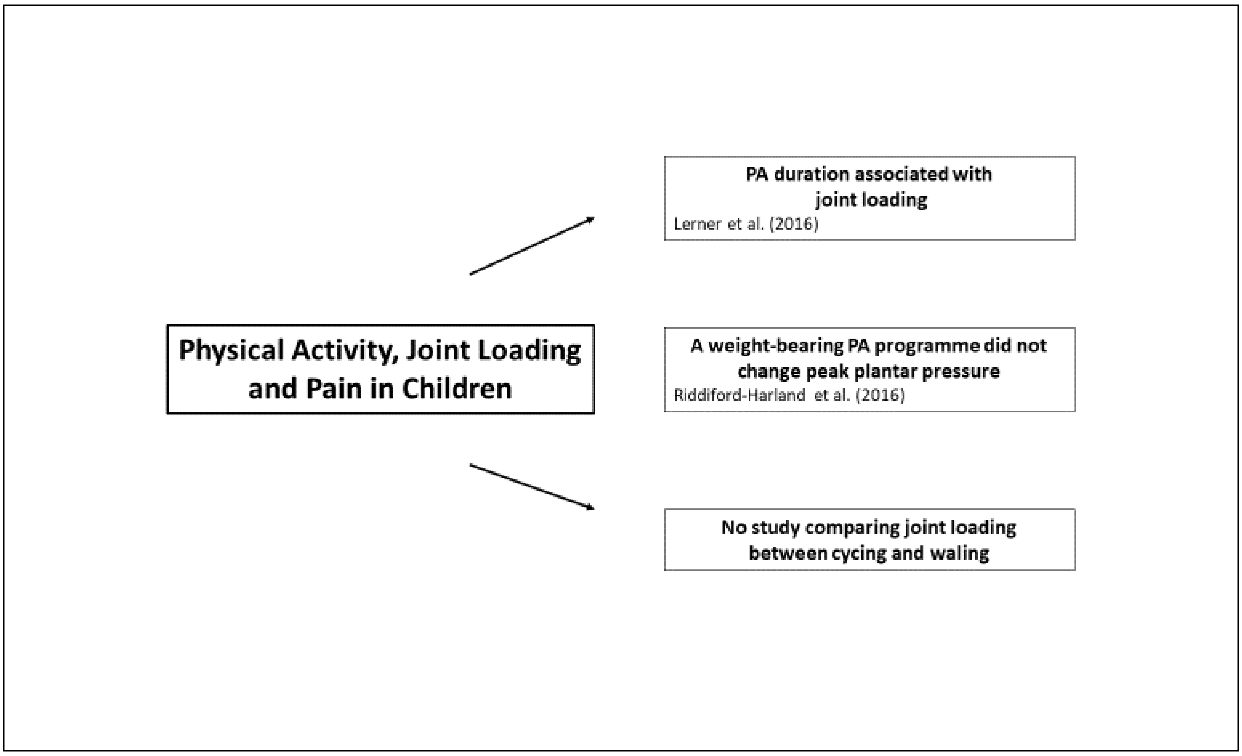


Figure 2.4 Diagram presenting the main findings on the association between joint loading, PA and pain in children.

Table 2.8 Summary of studies investigating the association between joint loading, PA and pain in children.

Reference	Country	Study design	Sample size	Description of participants	Summary of results
Lerner et al. (2016)	United States	Cross-sectional	20	Ten obese (6 males). Ten healthy-weight (5 males) Aged 8-12 years	During treadmill walking, medial compartment loading was 1.78 times greater in participants with OB than in healthy-weight participants. Body fat percentage and tibiofemoral medial-lateral force distribution had a strong linear relationship (r^2 = 0.79; P < 0.001). Modified changes in tibiofemoral loading during walking in participants with OB may increase the risk of knee pain and pathology.
Riddiford-Harland et al. (2016)	Australia	Descriptive	34	Male (29.4%) Mean age 8.5 years	A weight bearing PA programme did not alter the magnitude of peak plantar pressure distributions generated during walking. Children with OW and OB that had their body mass stabilised after a PA programme prevented increases in plantar pressure. Effect sizes not stated.

2.2.4 Question 4. Feasibility of cycling as a form of active commuting among children

Overall five studies, which in some form addressed the feasibility of cycling as a form of active commuting, were identified through the systematic search. Two studies had cross-sectional designs (Hansen, Eide, Omenaas, Engesaeter, & Viste, 2005; Kerr et al., 2006). One study had a qualitative approach (Ahlport, Linnan, Vaughn, Evenson, & Ward, 2008). One study had an intervention design (Ducheyne et al., 2013). Lastly, one study had a non-experimental design using quantitative and qualitative methods (Sisson, Lee, Burns, & Tudor-Locke, 2006).

Ahlport et al. (2008) conducted a qualitative study in the United States involving 37 boys and girls aged ten years. Parents were also involved in the study. The authors used separate semi-structured focus groups to collect information from parents and students regarding active commuting. Overall, parents and children reported three categories of barriers and facilitators for walking and cycling to school: intrapersonal and interpersonal characteristics of children and parents, neighbourhood environment and school policies and environment. Specific barriers and facilitators to cycling were not reported in this study. Some of the personal safety barriers reported by both parents and children were fear of kidnapping, fear of their children walking alone outside, fear of children getting involved in an accident and bullies. Personal safety facilitators reported by both parents and children were someone that could accompany children to school and a school early notification system. In this system, teachers have a telephone in the classroom and in case one student does not attend class, teachers can call parents as soon as possible. A motivation facilitator to walking or cycling to school was the chance to get exercise done. A motivation barrier was that children have to wake a bit earlier to get to school actively commuting. Environmental barriers were the lack of adequate sidewalks, bad weather, non-adequate terrain, traffic and long distance to school. Environmental facilitators were proximity to school, good weather and adequate sidewalks. School-related barriers were school policies that the schools had, i.e. children were not allowed to leave the school with their bicycles until all buses were gone and lack of crossing guards. School-related facilitators were crossing guards and heavy school traffic, i.e. being held in slow-moving traffic.

Sisson et al. (2006) conducted a non-experimental study using qualitative and quantitative methods to collect data from 14 schools in the United States. The authors explored biking prevalence, school biking policies and *Bikeability.* The biking prevalence was assessed in a preliminary study where the number of bicycles in racks, at schools, were counted during school hours for five consecutive days. Principals from schools participated in short interviews so that researchers could understand biking policies, i.e. rules related to helmet usage when using bicycles to get to schools. To identify the quality of infrastructure of neighbourhoods where children cycle, i.e. *Bikeability* assessment, the study mapped a 0.25-mile radius surrounding each school using the ArcView 3.2 Geographic Information Systems. Quantitative data showed that the prevalence of cycling was higher in school areas with less bus services than in areas where there were plenty of bus services (3.1 vs 1.3%; $p < 0.05$). Qualitative data indicated that one school had a formal biking policy. This policy specified streets and sidewalks that students were allowed or not to use. This school also did not allow bicycle usage, without parental authorization, to students who were enrolled below fourth grade. Two schools requested parental permission so that students were able to cycle to school. Three other schools established informal policies, i.e. guidelines that were not officially documented. For instance, students enrolled in grades below second grade were not allowed to cycle to school. Parental perspective on their children cycling to school was not assessed in this study.

Kerr et al. (2006) conducted a cross-sectional study in Canada involving 259 parents aged (mean) 44 years. The authors used a geographic information system and census data to compare neighbourhoods and judge them according to their infrastructure for walkability. Their analysis generated scores for both perceived and objective neighbourhood walkability scores. Some of the items included in a validated neighbourhood environment walkability scale used in the study were: street connectivity, aesthetics., residential density and cycling or walking facilities, e.g. presence of sidewalks and bicycle trails. The authors reported that the built environment (OR: 2.1; 95% CI: 1.12 to 3.97) and low parental concern (OR: 5.2; 95% CI: 2.71 to 9.96) were associated with children's active commuting. Parental concern on children’s active commuting was lower among parents of children aged 12 to 18 years ($p = 0.004$). Low parental concern regarding their children walking or cycling to school was associated with high walkability of neighbourhood (OR: 1.7; 95% CI: 1.00 to 2.85).

Ducheyne et al. (2013) used a different strategy to investigate cycling among children attending elementary schools. The authors quantitatively assessed the effects of cycling training sessions on children's cycling skills. An intervention study involving 102 boys and girls, aged 8 to 11 years, was carried out in Belgium. The intervention consisted of cycle training exercises to improve children's cycling skills. Improvements in children's cycling skills were identified according to their cycling skill scores. Although the authors reported that the cycle training programme showed significant effects on children's cycling skills ($F = 46.9$; $p < 0.001$), the feasibility of cycling to school among students *per se* was not included in this study. Additionally, the study did not include parental perspectives on children cycling in their research.

Hansen et al. (2005) also used a different strategy to investigate cycling among children. The authors quantitatively investigated the relationship between injuries and cycling and whether or not they were related to a child's age of debut in cycling. A cross-sectional study involving 957 boys and girls, aged 4 to 15 years, was conducted in Norway. The authors used questionnaires to collect information regarding children's cycling habits and to assess the incidence of injuries related to cycling. The questionnaire allowed participants to report from minor to severe injuries. The authors reported that the risk of getting injured during the first year of cycling can be reduced if children start to cycle at the age of 7 or 8 years instead of starting to cycle at the age of 4 or 5 years (HR: 0.78; 95% CI: 0.62 to 0.99; $p < 0.001$). Cycling more than three hours per week exposes children to a greater risk of suffering injuries during the first year of cycling when compared to peers who cycled less than one hour per week (HR: 2.75; 95% CI: 1.29 to 5.87; $p = 0.0125$). A limitation of this study was that parents used a questionnaire to report injuries and this might have led to bias.

2.2.4.1 Quality appraisal

The internal and external validity of cross-sectional studies can be seen in table 2.2 (Hansen et al., 2005; Kerr et al., 2006). The studies presented appropriate designs for stated aims. With regards to methods, both studies justified sample sizes and also clearly defined their reference population. Both studies randomly recruited large samples and they adopted selection processes that could clearly represent population under investigation. None of the studies presented measures to address and categorise non-responders. Both studies appropriately measured explanatory and outcome variables for the aims of the study. One study measured the explanatory and outcome variables using instruments that had been previously trialled, piloted or published (Kerr et al., 2006). The other study used a questionnaire for parents to report cycling habits of their children and the authors did report detail about the questionnaire, i.e. validity and reproducibility. One study clearly presented what was used to determine statistical significance and/or precision estimate (Kerr et al., 2006). One study did not sufficiently describe their methods, as the study did not state the level of significance adopted (Hansen et al., 2005). With regards to results, none of the studies adequately described the basic data, such as participants height, body weight and BMI. In both studies, it is not possible to know whether or not participants' response rate raises concerns about non-response bias as response rates in the studies were 52.3% (Kerr et al., 2006) and 79.8% (Hansen et al., 2005). Question number fifteen of the tool asks whether or not the results of studies were internally consistent. Results from all studies were internally consistent results. Both studies reported results of analyses that were previously described in methods. With regards to discussion, both studies had discussions and conclusions justified by the results. Both studies also discussed their limitations. In one study it was not possible to tell whether or not any funding sources or conflicts of interest may have affected the interpretation of results by the authors (Hansen et al., 2005). In the other study there were no funding sources or conflicts of interest that affected the interpretation of results by the authors (Kerr et al., 2006). Both studies obtained ethical approval and consent from participants.

Table 2.6 shows the quality appraisal of the case control study conducted by Ducheyne et al. (2013). The study clearly addressed a focused issue. The authors used an appropriate method to answer their question. The cases presented in their study were recruited in an acceptable way as schools that took part in the study were randomly selected and assigned to the intervention and control condition. The controls presented in their study were also selected in an acceptable way as they were likely to represent the population involved in the study. The exposure was accurately measured to minimise bias. The authors did not take into account potential confounding factors in their analysis.

Table 2.9 shows the quality appraisal of qualitative studies (Ahlport et al., 2008; Sisson et al., 2006). Both qualitative studies had clear statements of the aims of the research. The qualitative methodologies were appropriate in both studies. The research designs were appropriate to address the aims of the researches. The recruitment strategies were appropriate to the aims of the research in both studies. Data were collected in ways that addressed the research issues. In one study (Sisson et al., 2006) it was not possible to tell whether or not the relationship between researcher and participants was adequately considered, whereas in the other study the relationship between researcher and participants was adequately considered (Ahlport et al., 2008). In both studies, ethical issues were taken into consideration. The data analyses were sufficiently rigorous in both studies. Both studies also clearly state their findings. Lastly, both studies contribute to the body of literature investigating bicycling to school in children.

Table 2.9 Internal and external validity of qualitative studies.

Quality item	1	2	3	4	5	6	7	8	9
Qualitative study									
Ahlport et al. (2008)	Y	Y	Y	Y	Y	Y	Y	Y	Y
Sisson et al. (2006)	Y	Y	Y	Y	Y	?	Y	Y	Y

Y = Yes. N = No. ? = Can't tell. Questions 10 is descriptive and is not included in the table.

2.2.4.2 Summary

A summary of findings from the systematic search on the feasibility of cycling as a form of active commuting can be seen in figure 2.5 and table 2.10. Overall, there were only two studies examining barriers and facilitators of active commuting in children using a qualitative approach (Ahlport et al., 2008; Sisson et al., 2006). Ahlport et al. (2008) developed semi-structured focus group guides in order to collect qualitative data from parents and students in North Carolina. Participants were divided into two different groups: those who were active travellers and non-active travellers. Sisson et al. (2006) collected qualitative data in order to understand and gain insight on schools' biking policies, e.g. helmet usage policies, in Arizona. Principals from schools were invited to participate in short interviews. In the United States, there are policies for students to use school buses and bicycles to commute to school. Both studies were conducted in the United States, which suggests that their findings do not apply in England as policies for students to use school buses differ according to state laws (Ahlport et al., 2008; Sisson et al., 2006). Three further studies examined questions that relate to the feasibility of cycling. One found that a cycle training programme improved children's cycling skills (Ducheyne et al., 2013). One study identified that the built environment and parental concerns can influence whether or not a child actively commutes (Kerr et al., 2006). Another study reported that the prevalence of cycling was higher in areas with less bus services than in areas where there were plenty of bus services. These findings suggest that public transportation might influence whether or not a child uses cycling as a form of active commuting. Lastly, a study quantitively reported that the risk of getting injured during the first year of active cycling can be reduced if children start to cycle at the age of 7 or 8 years instead of starting at the age of 4 or 5 years (Hansen et al., 2005). We identified a lack of studies exploring the feasibility of cycling as a form of active commuting. Specifically, there is a paucity of studies investigating the perspectives of parents living in England, or more broadly the United Kingdom, regarding their children actively commuting to school.

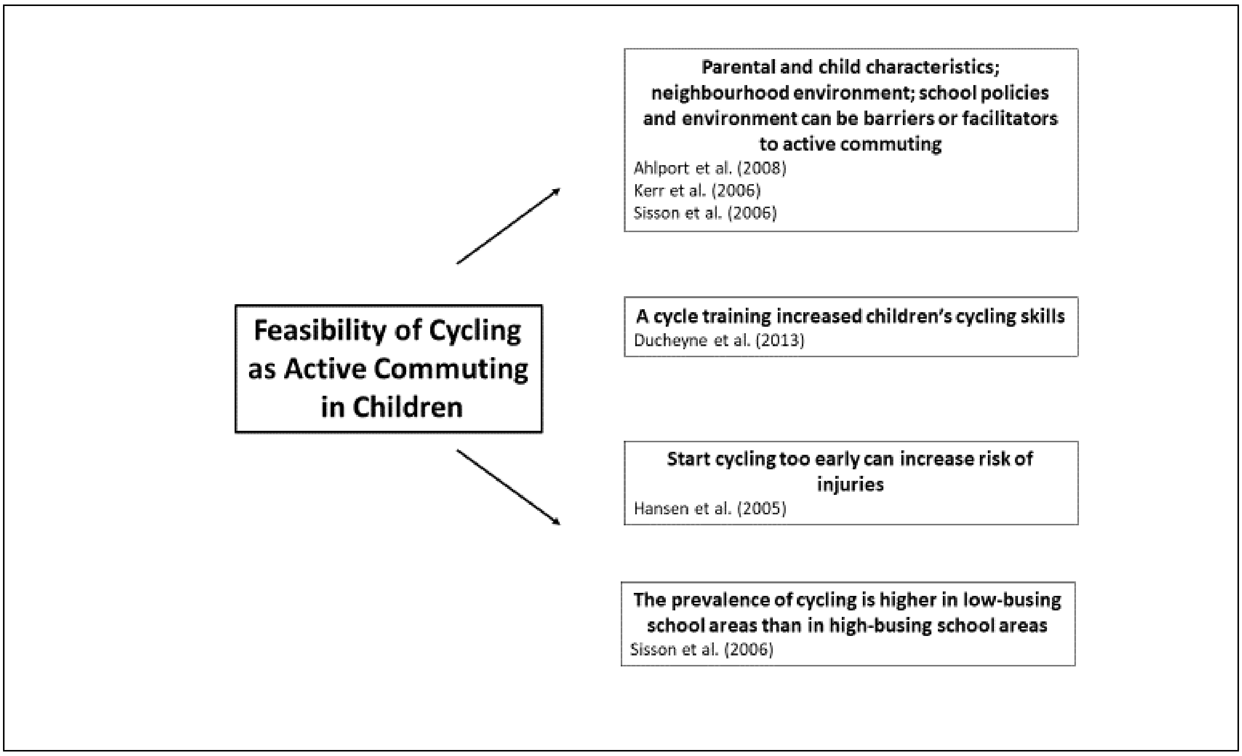


Figure 2.5 Diagram presenting the main findings on the association between joint loading, PA and pain in children.

Table 2.10. Summary of studies investigating the feasibility of cycling as a form of active commuting among children.

Reference	Country	Study design	Sample size	Description of participants	Summary of results
Ahlport et al. (2008)	United States	Qualitative	37 parents 37 children	Male (48.6%) Aged 10 years	Parents and children reported three categories of barriers and facilitators for walking and cycling to school: intrapersonal and interpersonal characteristics of children and parents, neighbourhood environment and school policies and environment.
Ducheyne et al. (2013)	Belgium	Intervention	N = 102 68 = intervention 34 = control	Male (50%). Aged 8-11 years. Healthy weight: 85%	The cycle training programme showed significant effects on children's cycling skills (F = 46.9; P < 0.001). A cycle training programme was effective to improve participant's cycling skills.
Hansen et al. (2005)	Norway	Cross-sectional	957	Male (50.5%) Aged 4-15 years	Risk of getting injured during the first year of active cycling can be reduced if children start to cycle at 7 or 8 years old instead of 4 or 5 years (HR: 0.78; 95% CI: 0.62 to 0.99; P < 0.001). Cycling more than three hours per week exposes children to a greater risk of suffering injuries during the first year when compared to peers who cycled less than an hour per week (HR: 2.75; 95% CI: 1.29 to 5.87; P = 0.0125).

Kerr et al. (2006)	Canada	Cross-sectional	259 parents	Mean age 44 years Male (50.6%) Children aged 5-18 years Boys (51.4%)	The built environment (OR: 2.1; 95% CI: 1.12 to 3.97) and parental concerns (OR: 5.2; 95% CI: 2.71 to 9.96) were associated with children's active commuting.
Sisson et al. (2006)	United States	Non-experimental Quantitative and qualitative data	14 schools	12.5 streets per school	The prevalence of cycling was higher in areas with low bus service than in areas where there were plenty of bus service (3.1 versus 1.3%; P < 0.05).

2.2.5 Limitations of the literature review

A systematic approach has been taken to searching the literature, identifying studies, and extracting data for this review, as previously outlined in this chapter. However, as a second reviewer was not available to independently screen and extract data the present review may not be considered a systematic review. The present review of the literature utilised two major electronic databases to perform systematic searches, i.e. PubMed and SPORTDiscus. Nevertheless, it is possible that eligible studies in the body of the literature were not included in the present review as they may have been published in journals that were not indexed in these electronic databases. Furthermore, it is also possible that eligible research was not included in the present review of the literature as it has only included studies that were published in English. Lastly, due to the fact that a large number of studies were published in the area of PA in children, the search strategy established for this review sought for studies that were published from January 1st of 2000 until July 31st of 2018. Therefore, it is also possible that eligible studies published out of the time range specified for the systematic searches were not included in the present review.

2.2.6 Strengths of the literature review

The present review of the literature had a comprehensive systematic search. Two major electronic databases were used to perform systematic searches in the current literature. Inclusion and exclusion criteria were established for retrieving studies in the body of the literature, which have contributed to retrieving relevant studies. The present review included not only original studies but also a systematic review that has been published in this area. The present review did not exclude studies according to their quality. Additionally, quality appraisal tools were used to assess studies that were included in the present review. This review of the literature included studies that have utilised subjective and objective measures for assessing PA. Lastly, no geographical limitation was set for retrieving studies published in this area. Thus, this review includes studies that have been published in different countries.

2.2.7 Conclusions

A total of twenty-seven studies were included in this review. Eleven studies on the association between PA and pain in children were retrieved. Nine studies on the association between PA and injuries in children were retrieved. Two studies on the association between joint loading, PA and pain in children were retrieved. No study on whether or not joint loading differs between cycling and other types of activities was identified. Lastly, five studies investigating the feasibility of cycling as a form of active commuting among children were retrieved. The following paragraphs will describe gaps and limitations in each area according to critical analyses carried out in the present review.

With regards to the association between PA and pain in children, the present review of the literature shows heterogeneous findings. Findings from a systematic review suggested consistent evidence for no association between PA and neck pain in school children, whereas the association between PA and low back pain in this population remains unclear (Sitthipornvorakul et al., 2011). A further study that objectively measured PA found no association between sedentary behaviour, MVPA and VPA with spinal pain cross-sectionally (Aartun et al., 2016). With regard to PA frequency, whilst there were studies that have suggested that self-reported participation in high levels of PA was associated with pain in children (Pereira et al., 2013; Silva et al., 2017; Watson et al., 2003), there were also studies that have indicated that self-reported participation in low levels of PA was associated with pain (Papadopoulou et al., 2014; Sollerhed et al., 2013; Swain et al., 2016). Engaging in self-reported MPA and VPA intensities has been associated with pain among children (Silva et al., 2017). Lastly, engaging in self-reported sedentary behaviour has also been associated with pain in children (Coleman et al., 2009; Martínez-López et al., 2015; Skoffer & Foldspang, 2008).

It is possible that the variation in study findings is related to the quality of the studies. The majority of studies in this area used subjective methods to assess PA in children, which are subject to significant recall bias and are likely to provide an inaccurate indication of PA in comparison to objective measures (Hidding, Chinapaw, van Poppel, Mokkink, & Altenburg, 2018). Additional issues with the quality of studies included small sample size (Sollerhed et al., 2013; Coleman et al., 2009; Silva et al., 2017), short period to identify PA influences on spinal pain (Aartun et al., 2016), self-reported variables such as body weight, height, PA and pain (Martínez-López et al., 2015; Papadopoulou et al., 2014; Pereira et al., 2013), analyses that did not differentiate acute pain experienced in the past seven days from chronic pain or pain of traumatic origin (Silva et al., 2017), search strategy retrieved publications in English only (Sitthipornvorakul et al., 2011). Further, the evidence is limited to only associations between PA and pain in a limited region, e.g. back pain, and no study examined whether or not the association between PA and pain differed according to weight status.

With regards to the association between PA and injuries in children, results from the present literature review also show heterogeneous findings. Evidence shows that VPA was associated with injuries (Clark et al., 2008; Lowry et al., 2007), whereas research also showed that MPA intensity was not associated with upper extremity injury (Nauta et al., 2017). One study found that participation in light PA was associated with decreased fracture risk among children (Ma & Jones, 2003) and participation in sedentary behaviour was associated with increased fracture risk (Ma & Jones, 2003). Practising unorganised activities and sports have also been associated with injuries (Spinks et al., 2006; Sundblad et al., 2005). Evidence also showed that a PA programme decreased the incidence of fracture among children (Fritz et al., 2016). Lastly, a study reported that high levels of PA were associated with low injury risk among children (Bloemers et al., 2012). Variability in study findings may be due to variability in the quality of studies. The majority of studies in this area investigated PA using subjective methods, with only one (Nauta et al., 2017) assessing PA using an objective measure. It is possible that the heterogeneity of results is due to measurement bias inherent in subjective measures of PA (Hidding et al., 2018). Additional issues with the quality of studies included limited assessment of injury regions, i.e. hand, wrist and forearm and upper arm (Ma & Jones, 2003), non-assessment of PA intensity (Moustaki et al., 2005), limited injury recall period, i.e. seven days (Nauta et al., 2017) and 10-14 weeks (Sundblad et al., 2005), and lastly injuries being reported by parents (Nauta et al., 2017; Spinks et al., 2006).

As with the studies examining the association between PA and pain, no study examined if children’s body weight status played a role in the relationship between PA and injuries. The association between PA and both pain and injuries may differ according to weight status because of increased joint loading during PA among children with OW or OB, compared to children with healthy weight. Additionally, associations between PA and pain and injuries may differ according to different intensities of PA. For example, VPA may be associated with increased pain because vigorous intensity activities such as running may increase joint loading in comparison to light intensity activities. There is a need to investigate the association between PA intensity and pain and injury in children using an objective method for assessing PA. There is also a need to examine if this association differs according to a child's weight status.

With regards to the association between joint loading, PA and pain in children, recent evidence in the literature shows that PA duration was associated with joint loading (Lerner et al., 2016) and that a weight bearing PA programme did not change peak plantar pressure among children (Riddiford-Harland et al., 2016). Even though two studies examining this topic were retrieved, none of them assessed whether or not the type of PA was related to joint loading or the association between joint loading and pain. Therefore, the relationship between joint loading, PA and pain in children remains unclear. Similarly, with regards to joint loading differences between cycling and other physical activities in children, no study has aimed to answer this question. Therefore, it is concluded that joint loading differences between a non-weight bearing and a weight bearing activity have not yet been determined.

With regards to the feasibility of cycling as a form of active commuting among children, there were only two studies examining barriers and facilitators of active commuting in children using qualitative approaches (Ahlport et al., 2008; Sisson et al., 2006). These studies were conducted in the United States. The present systematic search did not retrieve studies in this field that were conducted in the United Kingdom. A study conducted in England using qualitative methods would allow the collection and analysis of data from parents, which would lead to further understanding on facilitators and barriers towards cycling as a form of active commuting for children living in England.

2.2.8 Summary

The PA recommendations for children living in England are well established in the literature (Department of Health Physical Activity Health Improvement and Protection, 2011). However, evidence shows that PA recommendations are not met by many children (Wilkie et al., 2016). To understand the issue holistically, we need to look at a number of relevant aspects that can prevent children from engaging in recommended PA.

In summary, the systematic search of the literature confirmed that the following questions remain unanswered:

1. What is the association between PA, pain and injury in children and do these associations differ between children with and without OW/OB?
2. What is the association between joint loading, PA and pain in children?
3. Does joint loading differ between cycling and other types of activities in children?
4. What is the feasibility of cycling as a form of active commuting among children?

The answers to these questions will provide a more appropriate basis to tackle the problem of physical inactivity among children. For example, by developing more effective and acceptable PA interventions and recommendations for this population. It also becomes clear that the issue of PA recommendations is multifactorial and that any PA recommendations for children derived from biomechanical or physiological findings need to be practical and implementable. Thus, to make effective PA recommendations physiological, biomechanical environmental and personal barriers need to be considered in parallel. Therefore, the overall of this thesis was to investigate the physiological and biomechanical mechanisms underlying weight bearing or non-weight bearing PA recommendations, specifically joint loading and pain, whilst taking environmental and personal barriers to cycling as a means of active commuting into consideration.

CHAPTER 3. MULTIMETHOD RESEARCH DESIGN

The present chapter presents information regarding the multimethod approach and justifies the use of this approach to answer questions raised in previous chapters. Specifically, this chapter outlines: 1) the reason a multimethod design was used in the present thesis, 2) the particular type of multimethod that was used in the present thesis, 3) the methodological issues and opportunities that the selected multimethod design raises, 4) how the three studies interlink and how they relate to the overall question addressed in this thesis.

3.1. Description of the multimethod design

Multimethod design or multiple methods design is employed in a research project when two or more studies use different methods in order to investigate a topic in a comprehensive mode and there is a goal of answering one or several questions to solve a problem (Morse, 2003, 2010). Multimethod design is described by Morse (2003) as the management of two or more studies in a major research project that are carried out separately.

In the present thesis, two quantitative studies were first conducted, and qualitative study followed these studies. I will now describe the three key principles that must be considered when conducting a multimethod design and discuss these principles in relation to the present thesis (Morse, 2003).

Principle 1: Identification of a theoretical drive of the research project

Principle one is with regards to the identification of the theoretical drive of a research project. All of the studies within a large research project should be on the same topic and have an ultimate goal, which can be to test or discover (Morse, 2003). The *theoretical drive* is known as the first way that a researcher approaches a research topic with an overall thinking. Overall, the term *drive* refers to the thrust or direction of a comprehensive design. The *theoretical drive* can be either deductive (where the goal is to test) or inductive (where the goal is to discover) (Morse, 2003).

The *inductive theoretical drive* is established when a researcher is working to discover something by trying to answer questions that might solve a problem (Morse, 2003).

For instance, in general, the questions can be similar to: What is occurring? What does it mean? What leads to this phenomenon? Even if minor elements of the research project are deductive or confirmatory the project as a whole may still have an *inductive theoretical drive* (Morse, 2003). When a research plan or programme has an *inductive theoretical drive* the main study or studies of the research project are more likely to be qualitative and, the overall research project agenda is to discover (Morse, 2003).

Differently, when the main drive of a research project is to test a theory or hypothesis, for instance, to answer questions related to *how many* or *how much* or to *assess relationships*, then this research project has a *deductive theoretical drive*. The research team is likely to be using quantitative methods. Even though the research project can have inductive items or include qualitative studies, its main plan is to test and has a *deductive theoretical drive* (Morse, 2003).

In summary, the mode of inquiry being used, as well as the overall agenda of a research project, should be taken into account by researchers during all stages of a research plan. Morse (2003) proposes that every research project or cluster of projects within a topic must have either a *deductive* or an *inductive theoretical drive,* i.e. they have a goal of either testing or discovery. They cannot be neutral, nor be evenly informed by deductive and inductive studies (Morse, 2003).

Principle 2: Developing explicit awareness of each project's influence

As previously described, during the execution of a research project the research team needs to be aware of whether they are *deductively* or *intuitively* managing data at all times. This is fundamental to successfully conclude a research plan that has a combination of different methodological strategies, i.e. quantitative and qualitative protocols. Authors need to understand what role each study will play within the research project separately. Thus, authors can follow the protocol of each study without violating assumptions of each method used in the research project (Morse, 2003).

Combinations of multimethod designs

There are four potential combinations for research projects with an *inductive drive*. Table 3.1 shows possible combinations for research projects with an inductive theoretical drive according to Morse (2003). Also, there are four possible combinations for research projects with a *deductive drive*. Table 3.2 shows possible combinations for research projects with a deductive theoretical drive according to Morse (2003). Briefly, the main method used in a research project will become explicit by the ultimate goal of the research, i.e. whether the research project is aiming to test or to discover. This will be illustrated by the usage of capital letters. Capital letters showing QUAL indicate that the research project has an inductive theoretical drive. Whereas capital letters showing QUAN indicate that the research project has a deductive theoretical drive.

Sequential designs are employed when methods are used in a sequence. In this case, the main method, quantitative or qualitative, used to provide theoretical leadership for the project is commonly conducted primarily. A second method is then designed to obtain more data that the first method could not provide in the first studies, to provide more knowledge with regards to the overall research question or to obtain a logical expansion from data gathered in a previous study (Morse, 2003). While conducting a research project using a sequential design with an inductive drive, supplementary studies may be added to the research project to confirm a hypothesis. In certain situations, additional studies may have different protocols or include different variables and require additional ethical clearance (Morse, 2003).

Simultaneous designs are employed when methods are used concomitantly. In this case, one approach, quantitative or qualitative, will lead the theoretical background of the project. In other words, one method will form fundamental basis for the entire project. This fundamental basis for a project is developed in early stages of a project, i.e. design phase. A supplementary or an additional study can be proposed in order to obtain or clarify data that the project's main approach will not provide or be able to explain alone (Morse, 2003).

Table 3.1 Combinations for researches with an inductive theoretical drive.

1. QUAL + qual	
	Research using two qualitative methods concomitantly. One of the studies is dominant or is the base for the whole project.
2. QUAL → qual	
	Research using two qualitative methods in a sequence. One of the studies is considered the main study.
3. QUAL + quan	
	Research using a qualitative and a quantitative method concomitantly. The research project has an inductive theoretical thrust.
4. QUAL → quan	
	Research using qualitative and quantitative methods in a sequence. The research project has an inductive theoretical thrust.

Table 3.2 Combinations for researches with a deductive theoretical drive.

1. QUAN + quan	
	Research using two quantitative methods concomitantly. One of the studies is the main study.
2. QUAN → quan	
	Research using two quantitative methods in a sequence. One of the studies is considered the main study.
3. QUAN + qual	
	Research using quantitative and qualitative methods concomitantly. The research project has a deductive theoretical drive.
4. QUAN → qual	
	Research using quantitative and qualitative methods in a sequence. The research project has a deductive theoretical drive.

Principle 3: Considering methodological integrity

One of the fundamental aspects of the multimethod design is that each method should not be altered. Specifically, each method used in a research project should not have their assumptions violated, e.g. selection and size of sample for each method should be respected.

Strengths and challenges of Multimethod Design Research

The main strength of the multimethod design is that it can comprehensively answer a research question that can be multifactorial. Essentially, employing a combination of methods can potentially provide robust evidence to help solving a problem. This contribution is possible as the multimethod design allows collecting and presenting data with a wide range and depth (Morse, 2003). For instance, a research project with an observational approach collecting data regarding a specific activity can have a supplementary study, where individuals can report their experiences during this activity. Even though the studies within a project are independent, they can provide substantial and a more comprehensive contribution than a research project with a singular study or using only one method (Morse, 2003). The challenges related to multimethod design research mainly related to the researcher skills, time and resources. To conduct a research study using multimethod design it is necessary that the researcher and the research team involved are familiarised with data collection as well as data analysis from both quantitative and qualitative approaches.

3.2. Differences between multimethod and mixed methods design

The mixed methods approach is defined as the inclusion of several quantitative and qualitative strategies in a single project. Characteristics that seems to best define this method include: data collection and analyses of both qualitative and quantitative data in to order to answer research questions and hypothesis; combination of the two types of data and respective results; organisation of different actions into a research project to provide logic to conduct a study and lastly, framing these steps with appropriate philosophy and theory (Cresswell & Plano Clark, 2017). The main difference between mixed methods designs and multimethod designs is that studies in a research project using multimethod designs are independently concluded (Morse, 2003). The research question or hypothesis directs the research project, yet the entire research project is composed of two or more associated or complementary studies. In general, the research project will have either a *deductive* or an *inductive theoretical drive* and studies within this major research project are independent and will be conducted concurrently or sequentially. The plan will always take into account the fact that there is a major project with an inductive or a deductive drive and aims to answer one or more research questions (Morse, 2003).

The emerging conceptual scheme will be informed by the *results* section of each method, quantitative or qualitative, while findings are described according to the research question of the project. In a research project using multimethod design, data are not commonly connected from one study to another (Morse, 2003). Differently, in research projects using mixed methods designs, for instance, the research team can convert textual data into numerical data and further use this evidence when analysing data of a quantitative chapter of a thesis (Morse, 2003). On the other hand, in a research project or thesis using a multimethod design, studies are individually planned and organised to answer sub-questions. In multimethod research design, each method is conducted and completed in itself. Results from studies are triangulated in order to provide understanding as a whole (Morse, 2003).

3.3. Use of a multimethod design in the current thesis

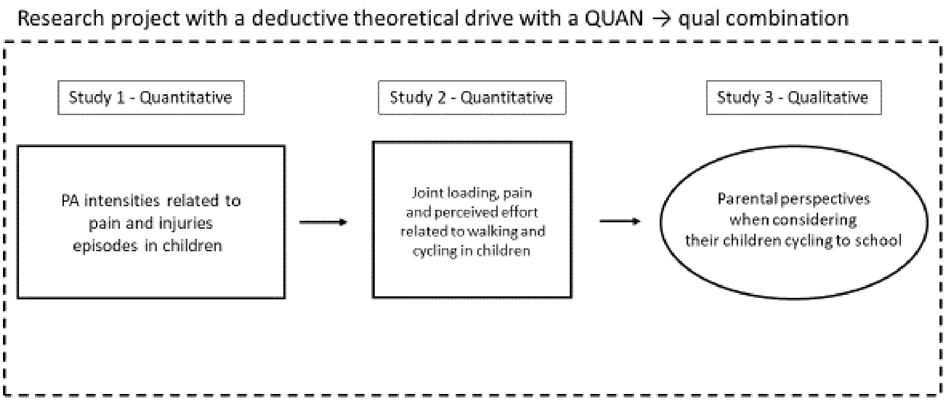
The present thesis used a multimethod research design with a QUAN → qual combination. Briefly, in this combination, quantitative studies are first conducted and are followed by a qualitative study. These studies are separately conducted in a sequence in a major research project with a deductive theoretical drive, even though the third study is an inductive investigation (Morse, 2003). The overall goal of this thesis was to investigate associations between PA, pain, injuries and, joint loading in children, and how these factors may affect recommendations regarding the type of PA that children should perform whilst taking environmental and personal barriers into consideration. The QUAN → qual design was appropriated to achieve this goal to quantitatively inform PA recommendations for children, by investigating the association between PA, pain, injuries. Also, to quantitatively estimate joint loading and pain from two different activities in children. Lastly, to explore barriers to active commuting on a bicycle as a means of PA for children a study with qualitative methods was used. Figure 3.1 illustrates the research design used in the present thesis to understand this problem and present results in a comprehensive mode.

Overall, the two first studies in the present thesis were quantitative studies. The first study aimed to assess the relationship between PA, pain and injuries, respectively, among children. Specifically, it examined if the duration of time spent in MPA and VPA, respectively, was associated with pain and injuries, and if these associations differed between children with and without OW and OB. We hypothesised that more intense PA may be associated with greater joint loading, and therefore increased time spent in VPA would be associated with a higher level of PA and higher number of injuries. We also hypothesised that the association between PA and pain and injuries would be greater among children with OW or OB compared to those with healthy weight, because children with OW or OB experience greater joint loading during PA. Greater joint loading during PA may lead to greater pain and increase the incidence of injuries.

The second study examined this hypothesis further, by investigating the association between PA type, joint loading and pain among children. We hypothesised that PA type may predict joint loading, even when the intensity of PA was identical, and this may lead to pain. Specifically, we examined if joint loading in lower limbs and pain differed between weight bearing and non-weight bearing activities among children. We also examined the difference in pain and perceived effort experienced by children while performing walking on a treadmill and cycling on a cycle ergometer. We hypothesised that children would experience less pain and demand less effort while cycling on a cycle ergometer than during treadmill walking.

Following these studies a last study, using a qualitative approach, aimed to explore barriers that children face to using bicycles for active commuting. This study was generated from our findings in the first two studies and was included to bring important insight to the overall aim of the thesis. The purpose of this study was to develop an understanding of why, despite the increase in cycling programmes in the UK and potential benefits of cycling over walking in terms of pain, regular participation in cycling is low. Specifically, we explored perspectives that parents have on the barriers to cycling as a form of active commuting to school.

Figure 3.1 Diagram showing the research strategy used in the present thesis.



CHAPTER 4. ARE MODERATE PHYSICAL ACTIVITY AND VIGOROUS PHYSICAL ACTIVITY RISK FACTORS FOR PAIN AND INJURIES IN CHILDREN?

4.1 Introduction

As previously indicated by findings from the systematic review, the literature is not clear regarding whether or not PA is associated with pain or injuries in children. Few studies have examined the association between duration and intensity of PA and pain. Those that did, mostly used subjective measures of PA, which likely are inaccurate at measuring the duration and intensity of PA (Hidding et al., 2018). Only one study has examined the association between objectively measured PA and pain in children (Aartun et al., 2016). However, this study focused only on neck and back pain and did not look at the association between moderate intensity PA (MPA) and pain, and vigorous intensity PA (VPA) and pain separately. Furthermore, no study has explored if the association between PA and pain differs according to weight status.

With regards to the relationship between PA and injuries, only one study objectively assessed PA (Nauta et al., 2017), but the study focused on upper extremity injuries only. In addition, the association between sedentary time and injuries and time in MVPA and injuries was examined, but not MPA or VPA separately. No study in the current literature has objectively investigated whether or not PA intensity is associated with injury of any body part in children or if this relationship differs according to body weight status in children. Thus, the present study aimed to investigate whether MPA and VPA are associated with pain and injuries in children and whether these associations differ between children with and without OW and OB.

4.2 Methodology

4.2.1 Study design

A cross-sectional design was used to investigate the association between PA, pain and injuries among children. Cross-sectional studies are an appropriate study design to examine associations between exposures and outcomes at one point in time because they are relatively quick and cheap to conduct (Webb & Bain, 2011). However, a cohort study design is more appropriate for determining the direction of association as the exposure is measured before the outcome. The study took place in

London, England, and data collection occurred from December of 2016 until March of 2017.

Recruitment strategy

First, the PhD researcher went to the administrative headquarters of the London Borough of Hillingdon in order to meet with assistants and professionals of the health and family sector of the borough. A first meeting was arranged, and the research project was then introduced and explained to attendants of the meeting by the PhD researcher and his supervisor. After understanding the importance of the project, access to the Fit Teen Club was granted. The Fit Teen Club is a physical activity programme for children that takes place at the Hillingdon Sports & Leisure Complex in Uxbridge, London. Due to minimum response from parents, as only few children were attending the Fit Teen Club scheme, no participant was recruited from this physical activity programme.

Supervisors of child weight management programmes in other areas of London were then contacted primarily by e-mails and phone calls. After arranging new face-to-face meetings to introduce the present research project to these supervisors, access to MyTime Active and North West London NHS Foundation Trust were granted in order to talk to parents of children. The PhD researcher offered to volunteer and provide help to Physical Activity Leaders at MyTime Active sessions. Volunteering support was provided during a three-month period at different physical activities sessions by the PhD candidate. Only one parent from MyTime Active agreed to let their children take part in the study. At the same time, the PhD candidate presented the research project to other physical activity clubs offering activities for children. The Hillingdon Triathletes club was contacted, and they agreed to share flyers inviting members and friends of the club to take part in the study. The Slipstreamers cycling club, where the PhD researcher also volunteered for three months prior to data collection, was also contacted. The Slipstreamers cycling club allowed the PhD candidate to talk to parents about the research project.

While offering voluntary help or assist in the physical activity clubs described above, the PhD researcher gathered information about all primary and secondary schools in the London Borough of Hillingdon. A total of 50 primary schools and 21 secondary schools were identified. The procedure adopted to contact schools in order to introduce the study and potentially recruit participants was: 1) send a detailed e-mail containing information about the present study to each of the 71 school e-mail addresses that were obtained from school websites; 2) to telephone each school in order to talk to head teachers and arrange meetings to personally introduce the study due to the lack of response after contacting schools via e-mail; 3) to provide some schools with further information as requested, i.e. an official letter via traditional postal service to consider participation in the study. However access to recruit students was declined. After trying to recruit participants from schools, help was sought from the Widening Access Department at Brunel University London. The department connected the research team with three schools in the London Borough of Hillingdon. Also, internal e-mails were sent to staff of Brunel University London that had children. Three major schools indicated interest in helping with participant recruitment. The three schools together had approximately 1,095 students enrolled aged 8 to 12 years. Initial meetings with head teachers were arranged in order to introduce the study. Seminars on PA were delivered to students in schools. The seminars were also used as a way of inviting students to take part in the study. Headteachers were provided with consent forms to send to parents. The recruitment process described lasted for 18 months. The present study received ethical approval (see appendix IV) from the Department of Life Sciences Research Ethics Committee at Brunel University London (reference number 2440-MHR-Mar/2016-2773-2).

4.2.2 Participants

A convenience sample of children who met the eligibility criteria was identified. To be included in the study children had to be aged 8 to 12 years. Children were excluded if they had a disability or medical condition that prevented them from engaging in daily physical activities such as physical education in school. The *Physical Activity Readiness Questionnaire* (PAR-Q) (Shephard, 1988) was used to assess any physical impairment or medical condition that would prevent participants from engaging in usual daily physical activities, such as playing outdoor games or participating in physical education classes (Mattocks et al., 2007).

4.2.3 Procedure

Data collection was divided into two parts: 1) on the first day, participants had the opportunity to ask questions about the study. The consent form signed by parents (see appendix V) and assent forms signed by children (see appendix VI) were collected. Accelerometers, PA diaries and instruction sheets about accelerometer usage were distributed; 2) after seven days, the accelerometers and the PA diaries were collected. Anthropometric measurements were then assessed and questionnaires regarding pain, injury and socioeconomic status were completed by the participant.

4.2.3.1 Body composition

All the anthropometric measurements were collected by a single researcher at the schools where the study took place. Stature was measured to the nearest 0.1 cm using a calibrated stadiometer (Charder HM200P Portstad Stadiometer) and body weight was assessed to the nearest 0.1 kg using a calibrated electronic weight scale (Seca, Hamburg, Germany). BMI was calculated as weight (in kg) divided by stature (in m) squared. OW and OB were classified according to the extended international (International Obesity Task Force) BMI cut-offs for thinness, OW and OB proposed by Cole & Lobstein (2012). According to the International Obesity Task Force, BMI cut-offs for classifying children as OW or OB differ according to the sex and age of a child (Cole & Lobstein, 2012). The International Obesity Task Force used BMI data from six countries to construct specific centile curves that are able to represent thinness, OW and OB representative of BMI at age 18 and above (Cole & Lobstein, 2012). Circumferences of waist and hip were collected using a Gulick anthropometric tape (Creative Health Products, Plymouth, USA). Measurements of waist and hip circumferences were recorded to the nearest 0.1 cm. Waist circumference was measured horizontally at the midpoint between the inferior border of the bottom rib and the top end of the iliac crest. Hip circumference was measured around the broadest portion of the buttocks with the tape positioned parallel to the floor (World Health Organization, 2008). Body fat was assessed using skinfold measurement. Skinfold measurement of the triceps and medial calf sites were collected on the right side of the body using a Harpenden Skinfold Caliper (Country Technologies). Body fat of participants was estimated by the relative body fat for girls and boys using specific equations proposed by Slaughter et al. (1988) (see appendix VII).

4.2.3.2 Socioeconomic status

Socioeconomic status of participants was assessed using the Family Affluence Scale (Currie et al., 2008) (see appendix VIII). The Family Affluence Scale is a questionnaire developed specifically for young students and it aims to reflect money expenditure of a family (Currie, Elton, Todd, & Platt, 1997). The questionnaire was updated in 2008 and was found to be reliable and suitable for students (Currie et al., 2008). Essentially, the Family Affluence Scale explores socioeconomic inequalities by classifying a set of items that reflects a family's assets and consumption. The questionnaire considers items such as the number of cars that a family possesses, whether a child owns their own bedroom, the number of times that their family went on holidays during the past 12 months and the number of computers their family has. This questionnaire has been widely used in children (Voráčová, Sigmund, Sigmundová, & Kalman, 2016; Frasquilho, De Matos, Marques, Gaspar, & Caldas-De-Almeida, 2017) and also in research exploring similar variables, i.e. the occurrence of injuries and PA (Pickett et al., 2005; Warsh, Pickett, & Janssen, 2010). After children responded to the questionnaire a factor score from zero to nine was attained, this score was then subsequently categorised into tertiles representing low, middle and high affluence groups: 0 to 3 low, 4 to 6 middle and 7 to 9 high (Currie et al., 2008).

4.2.3.3 Assessment of injury

The definition of an injury is widely accepted as an "event that requires medical attention" (Pickett et al., 2005; Pickett, 2005; Warsh, Pickett, & Janssen, 2010). Children and adolescents can get injured or hurt due to several daily common activities such as playing games and practising sports at home or at school. Injury episodes reported by participants do not include any case of illness such as Flu or Measles (Pickett et al., 2005). The literature is consistent with exploring injury episodes among children and adolescents by using a single question (Bloemers et al., 2012; Pickett et al., 2005). Thus, in the present study participants were asked to report injury events that required medical attention from a doctor or a nurse over the past 12 months (see appendix IX). The following question was asked: "During the past 12 months, how many times were you injured and had to be treated by a doctor or nurse?" Injury in children has been widely investigated using this question (Addor & Santos-Eggimann, 1996; Pickett et al., 2005; Warsh, Pickett, & Janssen, 2010).

4.2.3.4 Assessment of pain

Paediatric pain has been previously described as a subjective issue and is commonly reported by healthy children (Anthony & Schanberg, 2003). Participants were asked to self-report any pain or discomfort, of the whole body, that they experienced over the seven days of testing using a visual analog scale from the validated Pediatric Pain Questionnaire (Gragg et al., 1996; Varni, Thompson, & Hanson, 1987) (see appendix IX). This method consists of participants marking a point on a 100 mm horizontal line with several faces representing “no pain” to “severe pain” (Cohen et al., 2008). Visual analog scales have been widely recommended as the most appropriate method for assessing pain in children (Huguet, Stinson, & McGrath, 2010; Stinson, Kavanagh, Yamada, Gill, & Stevens, 2006). It is the most extensively validated method used for assessing pain in children and adolescents (Rapoff, 2003).

4.2.3.5 Accelerometry

PA was assessed using a triaxial ActiGraph wGT3X-BT accelerometer (Pensacola, USA). The ActiGraph wGT3X-BT monitor is a small (4.6 cm x 3.3 cm x 1.5 cm) and very light-weight device (19 g). The placement of the PA monitor plays an important role when assessing PA. While several studies do not report the specific placement of the monitor, it should be attached as close as possible to the centre of mass of the body (Trost et al., 2005). Trost, Mciver, & Pate (2005) documented that the best location for accelerometers to be placed is on the hip. Thus, participants were requested to wear the accelerometer around their waist, at the right hip (see figure 4.1) except for when swimming, showering or during other water activities and during all non-wake hours. Loss of data from the accelerometers, e.g. participants not wearing the monitor for all seven days, was expected. Therefore participants were asked to wear it for seven days (Trost et al., 2005) in order to obtain valid data for at least three days. Evidence has shown that, when using accelerometry, two to three days of monitoring PA are required to attain a reliability coefficient of 0.70 in primary school children (Trost, Pate, Freedson, Sallis, & Taylor, 2000). Thus, an average of at least three days was used to report children’s PA (Ekelund et al., 2006; Lebacq et al., 2016). A cut-off of at least 500 minutes of PA per day was adopted in order to obtain reliable data (Hinkley et al., 2012). Children who failed to record at least three days of at least 500 minutes of PA were excluded from further analyses.

Figure 4.1 A child wearing a triaxial ActiGraph wGT3X-BT accelerometer on the hip.

A 5-second epoch and sampling rate of 30 Hz was used in the present study as children tend to engage in different intensities of PA in very short bursts, i.e. lasting less than 15 seconds (Heil et al., 2012). The Actilife 6® software was used to download and process all data recorded with the accelerometers. An upper limit of 20,000 counts per minute was established as a threshold to avoid spurious data or monitor failure (Haapala et al., 2016; Heil et al., 2012). Non-wear time was defined as 60 minutes or more of consecutive zero counts. Minimum wear time per day was established as at least 500 minutes of recorded PA per day (Haapala et al., 2016), as this cut-off has been advised to obtain reliable PA data in children (Hinkley et al., 2012). MPA and VPA were assessed. PA cut-points were defined as 3581 to 6129 counts per minute for MPA (Mattocks et al., 2007) and ≥6130 counts per minute for VPA. These PA cut-points were documented by Mattocks et al. (2007) and were validated in British children performing free-living activities (Golding, Pembrey, Jones, & Team, 2001).

4.2.4 Statistical analysis

The distribution of variables was assessed using Q–Q (quantile-quantile) plots and histograms. Variables that were normally distributed were described using means and standard deviations. Variables with skewed distributions were described using medians and interquartile ranges. Categorical variables were presented as frequencies and percentages.

To examine whether there was any difference between the number of pain episodes reported by children with and without OW/OB, an independent two-sample *t*-test was performed. To examine whether there was any difference between injury incidence in children with and without OW/OB, the Mann–Whitney *U* test was performed.

Confounding variables have been commonly defined in the literature as variables that affect both the independent and dependent variable leading to false associations (VanderWeele & Shpitser, 2013). Potential confounding variables were identified based on *a priori* knowledge of associations between PA, pain and injuries. These variables were age, socioeconomic status, sex, waist, BMI, hip, and body fat. Socioeconomic status was categorised as low, middle and high affluence groups and BMI as healthy weight and OW/OB. Additionally, injury was considered as a potential confounder of the relationship between PA and pain. Exploratory analyses were conducted using Poisson and linear regressions, respectively, to examine the associations between PA (both MPA and VPA) and potential confounders, between pain and potential confounders, and between injuries and potential confounders.

To explore the effect of adjusting for potential confounders on the association between PA (MPA and VPA, respectively) and pain, we firstly fitted linear regression models with PA as the independent variable and pain as the dependent variable. We then included potential confounders one at a time to see how the coefficient for PA changed with the inclusion of a potential confounder. We decided *a priori* that variables that changed the coefficient for PA by more than 5% would be included in the final models. Similarly, negative binomial models were fitted with PA (MPA and VPA, respectively) as the independent variable and injury as the dependent variable and the process was repeated to identify confounding variables for the association between PA and injuries.

From this exploratory analysis, no potential confounder changed the coefficient for PA by more than 5%. However, based on the previously stated definition of a confounding variable, we identified that age, sex, socioeconomic status, injuries and OW/OB are potential confounders of the association between PA and pain, and that age, sex, socioeconomic status and OW/OB are potential confounders of the association between PA and injuries. This was based on previous research that identified that:

1. Age was associated with PA (Prista et al., 2009) and pain (Myers et al., 2006)
2. Sex was associated with PA (Wei et al., 2017) and pain (Myers et al., 2006)
3. Socioeconomic status was associated with PA (Brockman et al., 2009) and pain (Fryer, Cleary, Wickham, Barr, & Taylor-Robinson, 2017)
4. Injury was associated with PA (Nauta, Martin-Diener, Martin, Mechelen, & Verhagen, 2015) and pain (van Meijel et al., 2019)
5. OW/OB was associated with PA (Janssen, Katzmarzyk, Boyce, King, & Pickett, 2004) and pain (Deere et al., 2012)

1. Age was associated with PA (Prista et al., 2009) and injuries (Costa e Silva, Fragoso, & Teles, 2017)
2. Sex was associated with PA (Wei et al., 2017) and injuries (Verhagen, Collard, Chin, Paw, & Van Mechelen, 2009)
3. Socioeconomic status was associated with PA (Brockman et al., 2009) and injuries (Pickett et al., 2005)
4. OW/OB was associated with PA (Janssen et al., 2004) and injuries (Pomerantz, Timm, & Gittelman, 2010)

The addition of waist circumference, hip circumference and body fat percentage, respectively, to adjusted models made no difference to the effect estimates and these variables were therefore not adjusted for in final models.

In summary, to examine the association between PA (MPA and VPA, respectively) and pain, we fitted separate linear regression models. Univariable models were fitted firstly to examine the unadjusted association between PA and pain. Multivariable models were fitted secondly to examine the association between PA and pain, adjusted for age, sex, socioeconomic status, injuries and OW/OB.

To examine the association between PA (MPA and VPA, respectively) and injuries, we fitted separate negative binomial models. Univariable models were fitted firstly to examine the unadjusted association between PA and injuries. Multivariable models were fitted secondly to examine the association between PA and injuries, adjusted for age, sex, socioeconomic status and OW/OB. Negative binomial models were fitted instead of Poisson models as there was evidence of overdispersion (Greene, 2008).

To examine whether being OW/OB modified the association between PA and pain, and between PA and injuries, respectively, MPA-by-OW/OB and VPA-by-OW/OB interaction terms were added to the final models.

Residual plots were examined following linear regressions to identify if assumptions of homoscedasticity, normality and linearity were violated. Statistical analyses were performed using the statistical software STATA (StataCorp LLC, College Station, Texas, USA), version 13 (see appendix X).

4.3 Results

Of the 1,095 students aged 8 to 12 years enrolled in the three schools, 114 children consented to participate. No child was excluded from the study, i.e. based on their response to the PAR-Q. Eight students were not included in the final analyses, as they failed to record at least three days of PA. Therefore, 106 children were included in final analyses. The characteristics of participants are described in Table 4.1. Sixty-eight children (64.2%) had healthy weight and 38 children (35.8%) had OW/OB. No difference in pain was found between children with (Mean (SD)=1.18 (1.77)) and without OW/OB (Mean (SD)=1.41 (1.91); p=0.535). Similarly, no difference in the incidence of injuries was found between children with (Median=0, interquartile range=0 to 6) and without OW/OB (Median= 0, interquartile range=0 to 5); p=0.504). With regards to MPA, no difference was found between children with and without OW/OB (p=0.959). Likewise, no difference was found in VPA between children with and without OW/OB (p=0.947).

Table 4.1 Characteristics of participants.

	Healthy weight n=68		OW/OB n=38		Total n=106	
	Mean	**(SD)**	**Mean**	**(SD)**	**Mean**	**(SD)**
Age (years)	10.4	1.3	10.4	1.1	10.4	1.2
Body mass (kg)	34.5	7.8	49.3	10.3	39.5	11.4
Stature (cm)	142.2	10.5	147.2	11.8	143.8	11.2
BMI (kg/m^2)	16.9	2.1	22.5	8.6	18.8	3.4
Waist circumference (cm)	54.2	16.5	61.7	20.6	56.2	18.4
Hip circumference (cm)	62.0	19.5	68.0	23.4	63.5	21.3
Pain (over the past seven days)	1.2	1.8	1.4	1.9	1.3	1.8
Injury (over the past 12 months)[a]	0.0	0.9	0.0	1.2	0.0	1.1
Body fat (%)	22.1	6.0	33.1	8.6	25.9	8.9
MPA (min/day)	100.6	48.4	100.1	53.0	100.4	49.8
VPA (min/day)	33.4	26.2	33.1	22.1	33.3	24.7
Socioeconomic status (%)						
Low	13.9		11.9		13.2	
Middle	54.2		40.5		49.1	
High	31.9		47.6		37.7	

[a] = Median and interquartile range. Pain score 0 to 10. Injury = Number of injuries over the past 12 months.

4.3.1 PA and pain

4.3.1.1 MPA and pain

Table 4.2 presents linear regression models regarding MPA and pain. Linear regression models revealed that there was no evidence that MPA was associated with pain in children (β=0.0004, 95% CI -0.007 to 0.008; p=0.915) even after adjusting the model for age, sex, socioeconomic status, OW/OB and injuries (β=-0.0005, 95% CI -0.008 to 0.007; p=0.887). Table 4.3 shows that there was no evidence that the association between MPA and pain differed according to weight status (p=0.909).

4.3.1.2 VPA and pain

Table 4.4 presents analyses investigating the relationship between VPA and pain in children. Unadjusted and adjusted analyses revealed that VPA was not a predictor of pain in children (adjusted β=0.0054, 95% CI -0.009 to 0.020; p=0.468). There was also no evidence that weight status modified the association between PA and pain (Table 4.5; p=0.881).

Table 4.2 Unadjusted and adjusted regression analyses investigating the relationship between MPA and pain in children.

	Pain		
Dependent variable: pain	**β**	**95% CI**	***p*-value**
Model 1: MPA	0.0004	(-.007 to .008)	0.915
Model 2: MPA	-0.0005	(-.008 to .007)	0.887

Model 1: univariable analysis; Model 2: multivariable analysis adjusted for age, sex, SES, injury and OW/OB.

SES: Socioeconomic status; OW/OB: Overweight/obesity.

Table 4.3 Multiple linear regression model investigating the association between MPA and pain adjusted for potential confounding variables and including an interaction term between MPA and OW/OB to test for effect modification.

	Pain		
Dependent variable: pain	**β[a]**	**95% CI**	***p*-value**
MPA	-0.0088	(-.020 to .002)	0.118
MPA by OW/OB interaction	**0.0003**	**(-.005 to .005)**	**0.909**

[a]Coefficients are adjusted for age, sex, SES, injury and OW/OB.

SES: Socioeconomic status; OW/OB: Overweight/obesity.

Table 4.4 Unadjusted and adjusted regression analyses investigating the relationship between VPA and pain in children.

	Pain		
Dependent variable: pain	**β**	**95% CI**	***p*-value**
Model 1: VPA	0.0069	(-.008 to .022)	0.354
Model 2: VPA	0.0054	(-.009 to .020)	0.468

Model 1: univariable analysis; Model 2: multivariable analysis adjusted for age, sex, SES, injury and OW/OB.

SES: Socioeconomic status; OW/OB: Overweight/obesity.

Table 4.5 Multiple linear regression model investigating the association between VPA and pain adjusted for potential confounding variables and including an interaction term between VPA and OW/OB to test for effect modification.

	Pain		
Dependent variable: pain	**β[a]**	**95% CI**	***p*-value**
VPA	-0.001	(-.006 to .004)	0.759
VPA by OW/OB interaction	**-0.001**	**(-.013 to .011)**	**0.881**

[a]Coefficients are adjusted for age, sex, SES, injury and OW/OB.

SES: Socioeconomic status; OW/OB: Overweight/obesity.

4.3.1.3 MPA and injuries

Table 4.6 presents results of the analyses involving MPA and VPA, respectively, and the incidence of injuries in children. Table 4.6 revealed no association between MPA and the incidence of injuries (Rate Ratio (RR)=1.00, 95% CI 0.99 to 1.01; p=0.995), even after adjustment for confounders (adjusted RR=1.00, 95% CI 0.99 to 1.01; p=0.995). There was also no evidence that the association between MPA and injuries differed according to weight status (p=0.597; Table 4.7).

4.3.1.4 VPA and injuries

Table 4.8 show results of the analyses between VPA and the incidence of injuries in children. Analyses from negative binomial models revealed that VPA did not predict injuries in children (RR=1.00, 95% CI 0.99 to 1.02; p=0.798), even after adjusting for potential confounders (RR=1.00, 95% CI 0.99 to 1.02; p=0.868). There was also no evidence that weight status modified the association between VPA and injuries (p=0.735; Table 4.9).

Table 4.6 Negative binomial models investigating the unadjusted and adjusted associations between MPA and number of injuries in the past 12 months in children.

		Injuries	
Dependent variable: injury	**RR**	**95% CI**	***p*-value**
Model 1: MPA	1.00	(.99 to 1.01)	0.995
Model 2: MPA	1.00	(.99 to 1.01)	0.995

Model 1: univariable analysis; Model 2: multivariable analysis adjusted for age, sex, SES, injury and OW/OB.

SES: Socioeconomic status; Injuries = Number of injuries over the past 12 months; OW/OB: Overweight/obesity.

Table 4.7 Negative binomial models investigating the association between MPA and number of injuries in the past 12 months adjusted for potential confounding variables and including an interaction term between MPA and OW/OB to test for effect modification.

		Injuries	
Dependent variable: injury	**RR[a]**	**95% CI**	***p*-value**
MPA	1.00	(.99 to 1.01)	0.748
MPA by OW/OB interaction	**1.00**	**(.98 to 1.01)**	**0.597**

[a]Rate ratio is adjusted for age, sex, SES and OW/OB.

SES: Socioeconomic status; OW/OB: Overweight/obesity.

Table 4.8 Negative binomial models investigating the unadjusted and adjusted associations between VPA and number of injuries in the past 12 months in children.

	Injuries		
Dependent variable: injury	**RR**	**95% CI**	***p*-value**
Model 1: VPA	1.00	(.99 to 1.02)	0.798
Model 2: VPA	1.00	(.99 to 1.02)	0.868

Model 1: univariable analysis; Model 2: multivariable analysis adjusted for age, sex, SES, injury and OW/OB.

SES: Socioeconomic status; Injuries = Number of injuries over the past 12 months. OW/OB: Overweight/obesity.

Table 4.9 Negative binomial models investigating the association between VPA and number of injuries in the past 12 months adjusted for potential confounding variables and including an interaction term between VPA and OW/OB to test for effect modification.

	Injuries		
Dependent variable: injury	**RR[a]**	**95% CI**	***p*-value**
VPA	1.00	(.99 to 1.02)	0.755
VPA by OW/OB interaction	**0.99**	**(.96 to 1.03)**	**0.735**

[a]Rate ratio is adjusted for age, sex, SES and OW/OB.

SES: Socioeconomic status. OW/OB: Overweight/obesity.

4.4 Discussion

The purpose of this study was to investigate the association between PA, pain and injuries in children. We found that MPA and VPA were not predictors of pain or injuries in children. The association between PA and pain, and PA and injuries, respectively, also did not differ between children with and without OW/OB. In a systematic search of the literature we identified eleven reports that examined the association between PA and pain in children over the past 18 years. One was a systematic review (Sitthipornvorakul et al., 2011), nine studies had cross-sectional designs (Coleman, Straker, & Ciccarelli, 2009; Martínez-López et al., 2015; Papadopoulou, Malliou, Kofotolis, Emmanouilidou, & Kellis, 2014; Pereira, Castro, Bertoncello, Damiao, & Walsh, 2013; Silva, Sa-Couto, Queiros, Neto, & Rocha, 2017; Skoffer & Foldspang, 2008; Sollerhed, Andersson, & Ejlertsson, 2013; Swain et al., 2016; Watson et al., 2003), and one study had a prospective cohort design (Aartun et al., 2016).

Two studies have investigated the association between subjective PA intensity and pain in children. Silva et al. (2017) reported that more time spent in MPA was significantly associated with a higher probability of reporting pain on neck, shoulders, low back, wrists, hips, knees and ankles/feet. While more time spent in VPA was significantly associated with a higher probability of reporting pain on shoulders, mid back, knees and ankles/feet. Swain et al. (2016) found that reduced participation in MVPA was associated with presence of back pain, headache and stomach-ache in girls and also associated with combined headache and stomach-ache or headache in boys. In the present study, pain was not associated with moderate nor VPA in children. Only one study has previously investigated the association between objective PA intensity and pain in children. Similarly to findings of the present investigation, Aartun et al. (2016) found no association between PA and spinal pain cross-sectionally nor longitudinally. Aartun et al. (2016) examined a greater sample size than the one investigated in the present study (n=906). Thus, it is likely that the reason the present study did not find associations between PA and pain was not related to the sample size.

None of these studies has assessed whether or not the association between PA and pain differ according to body weight status of children. Results from the present study showed that the association between PA and pain did not differ according to a child's body weight status. Additionally, further contributions of the present study to the current body of the literature are not only the objective assessment of MPA and VPA, but that intensity of whole-body pain was assessed among children. Although we hypothesised that children with OW/OB may be more likely to experience pain during PA as a result of increased joint loading, the results of the present study do not support this hypothesis. This is even after considering different intensities of PA. It is possible that analyses of the present study did not support this hypothesis as PA type was not investigated in the present study. The literature shows that OW and OB are related to musculoskeletal pain in children (Stovitz et al., 2008). However, studies are needed to confirm whether or not PA type is associated with pain among children.

One study has investigated the association between subjective PA intensity and the incidence of injuries in children. Lowry et al. (2007) found that high frequency in MPA was associated with decreased odds (OR: 0.55; 95% CI: 0.33 to 0.92) of PA injury among boys with OW and medium (OR: 1.35; 95% CI: 1.01 to 1.81) and high (OR: 1.52; 95% CI: 1.12 to 2.04) frequency in VPA were associated with injuries among girls. One study has investigated the association between objective PA and intensity and the incidence of injuries. Similarly to findings of the present investigation, Nauta et al. (2017) found that PA, more specifically MVPA, was not a predictor of acute upper extremity injury risk. A limitation of this study was that the authors examined the association between MVPA and injury but did not separate associations between moderate and vigorous intensities of PA and injury. Children may be more likely to experience injury during VPA. The present investigation overcame this limitation and showed that VPA was not associated with the incidence of injuries in children. Nauta et al. (2017) used a greater sample size (n=1,048) than the present study. This demonstrates that the sample size used in the present study may not have affected statistical power in our analyses, where also no association between PA and injuries was found.

There are limitations to this study that should be considered. The present study had a cross-sectional design. A cohort study design would have provided more information about the direction of association as the exposure is measured before the outcome (Parfrey & Barrett, 2009). A power analysis was not performed in the present study. Performing a prospective power analysis can prevent a study from being statistically under or overpowered as the researcher can make a more precise decision regarding the sample size (Ellis, 2010). A larger sample and recruitment from a wider geographical area would allow better representation of the sample. Even though efforts were made to create partnerships with weight management organisations, as previously described, only a few schools were able to cooperate, and there was a relatively low proportion of children with OW/OB included. Additionally, we grouped children with OW/OB, rather than treating children with OB as a separate group, because there was a relatively small number of children with OB (n=5). The association between PA and pain, and PA and injuries may only differ between those with healthy weight and those with extreme OB. However, we cannot determine that from our data. Another limitation of the present study is that pain was measured over seven days when PA was also assessed. Measuring pain during or after specific weight bearing activities would possibly allow children to report pain or discomfort more accurately, i.e. pain that they may have felt during a specific activity. Similarly, children were asked to recall injuries over the past 12 months, which may be difficult to recall and result in inaccurate estimates of the number of injuries experienced.

This is the first study investigating whether objectively measured PA can predict whole body pain and examining if the association differs between children with and without OW/OB. One study has examined the association between objectively measured PA and pain (Aartun et al., 2016). However this study focused only on spinal pain, i.e. a questionnaire was used to recall neck, mid back and low back pain over, did not look at MPA and VPA separately and also did not assessed body weight of their participants. The present study overcame this limitation and examined whether pain in any body region was associated with PA. The systematic search conducted in the literature review of the present thesis indicated that no study has explored if the association between PA and pain differs according to weight status. Analyses in the present study included an interaction term that allowed us to assess whether or not the association between PA and pain differed according to a child's weight status. With regards to the relationship between PA and injuries, this study overcame limitations of previous studies investigating PA and injury in children with OW and OB where PA was self-reported (Bloemers et al., 2012; Clark et al., 2008; Fritz et al., 2016; Lowry et al., 2007; Ma & Jones, 2003; Moustaki et al., 2005). Only one study objectively assessed PA (Nauta et al., 2017), but the study focused on upper extremity injuries only. The present study also overcame this limitation and investigated whether PA is associated with injuries in any body region.

The present study is the first to examine the association between different PA intensities (MPA and VPA) and incidence of injuries. The incidence of injuries may be higher among people who engage in more intense PA, and it is, therefore, important to examine whether or not these intensities can lead them to experience injuries. Further, children with excess body weight may be more exposed to injuries as their lower limbs have to bear higher amounts of loading while practising physical activities. Findings from the present study, however, do not support the hypothesis that engaging in MPA or VPA is associated with the incidence of injuries. The findings also do not support the hypothesis that the association between PA and injuries differs for children with OW/OB, compared to those with healthy weight. These analyses suggest that it is safe for children who are OW/OB to follow PA guidelines (Department of Health Physical Activity Health Improvement and Protection, 2011). We believe that our analyses did not show any association between PA and pain as PA type was not included in our analyses.

There are recommendations for future research investigating these variables in children. First, it is recommended that research should assess whether pain and injury are related to PA in children considering the physical environment, i.e. inside or outside school and also consider type of activity practised. Second, research should examine these associations in children with OB, rather than OW/OB. Third, it is recommended a surveillance system to report pain and injury in real time, so that children do not need to recall long periods that they experienced pain or injuries. It is also recommended that research investigate the association between PA type and pain. Lastly, it is advised that research should investigate the association between PA intensity and acute pain, such as pain episodes while engaging in PA.

Findings from this study indicate that there is no evidence that MPA and VPA are associated with pain and injuries in children. Our results also suggest that the association of PA with pain and injuries does not differ between children with or without OW/OB.

CHAPTER 5. BIOMECHANICAL FACTORS UNDERLYING A WEIGHT BEARING AND A NON-WEIGHT BEARING ACTIVITY PERFORMED AT EQUIVALENT INTENSITIES BY CHILDREN

5.1 Introduction

Walking is a moderate intensity activity (Haskell et al., 2007; Landry & Driscoll, 2012; U.S. Department of Health and Human Services, 2008) that has been recommended for children and adolescents (Lafortuna et al., 2010) to promote physiological benefits and improve bone health (U.S. Department of Health and Human Services, 2008). While a certain amount of joint and bone loading is beneficial for healthy bone development, as it can contribute to optimising bone mass in children (Landry & Driscoll, 2012), there may be situations in which excessive or increased physiological forces in the joints can lead to pain and injury. In this case, non-weight bearing activity might be an alternative option for PA as it can evoke similar physiological benefits in children. Cycling, for example, has been shown to have benefits including the protection against excess body fat (Bere et al., 2011), improved cardiorespiratory fitness (Maher et al., 2012) and increasing physical abilities such as agility, balance and reaction response (Lirgg et al., 2018). Thus, in situations where there is a predisposition for joint overloading, pain or injury, non-weight bearing activities might be a more suitable mode of exercise to achieve similar physiological benefits, while reducing the risk for injury.

With this in mind, understanding the differences in joint loading and pain between walking and cycling will be a useful first step to tailor PA recommendations in relation to different paediatric populations. For example, those children who are more prone to lower limb injury or pain may be better advised to achieve their PA recommendations by means of non-weight bearing activities. No study to date has explored if joint loading or pain differs between walking and cycling among children

The main purpose of this study was to investigate differences in joint loading between walking and cycling, at similar physiological intensities in children, in order to compare activities that provide equivalent cardiovascular benefit. We hypothesised that the dependent joint loading variables would be greater during walking (weight bearing activity) than during cycling (non-weight bearing activity). A secondary purpose of this study was to determine the differences in perceived pain and effort between walking and cycling. We hypothesised that given excessive or increased physiological forces in the joints that may lead to pain, pain would also be greater during walking than cycling.

5.2 Methodology

5.2.1 Participants

Seventeen children (11 males) volunteered to participate in this study. The inclusion criteria were (1) to be aged 8-12 years and (2) to be able to cycle on a cycle ergometer and to walk on a treadmill. Exclusion criteria were any physical impairment that prevented the practice of regular PA, i.e. physical education classes or the practice of sports. The PAR-Q (Shephard, 1988) was used to assess any physical impairments or injuries in children. PA background of children was assessed using the validated (Kowalski, Crocker, & Faulkner, 1997) PA Questionnaire for Older Children (PAQ-C) (Crocker, Bailey, Faulkner, Kowalski, & McGrath, 1997). After reading consent and assent forms, written consent was obtained from parents (see appendix XI) and children (see appendix XII) prior to their participation in the study. The present study received ethical approval (see appendix XIII) from the Department of Life Sciences Research Ethics Committee at Brunel University London (reference number 0523-MHR-Jan/2016-1202). The recruitment strategy used in the present study can be found in the appendix section (see appendix XIV).

5.2.2 Anthropometrics

Stature was measured to the nearest 0.1 cm using a calibrated stadiometer (Charder HM200P Portstad Stadiometer) and body mass was assessed to the nearest 0.1 kg using a calibrated electronic weight scale (Seca, Hamburg, Germany). Standing height, sitting height and leg length were measured for assessing biological maturity. These variables are required to predict maturity offset according to predictive equations for boys and girls proposed by Mirwald et al. (2002) (see appendix XV). All participants were confirmed to be prepubertal. To adjust the bicycle setup for each participant, measurements of inside leg, standing torso height, arm length and medial malleolus to first metatarsal were obtained using the FitKit Inseam Measurement Device (Fit Kit Systems, Montana, USA). BMI was calculated as mass (in kg) divided by height (in m) squared.

5.2.3 Procedure

Participants were invited to attend the laboratory with their parents on one occasion. Data collection consisted of three different parts: 1) assessing anthropometric measurements of participants, 2) adjusting the stationary bicycle (Serotta International Cycling Institute, Boulder, CO, USA) according to the anthropometry of each child (see text below) and 3) the assessment of kinematics and kinetics during walking and cycling. Two methods were used to match physiological load. First, cardiovascular loads between walking and cycling were matched using heart rate (HR matched). A familiarization trial was performed on the treadmill and heart rate of children was obtained while they walked at a fast pace. Children were asked to walk on the treadmill as fast as they could. A submaximal test was performed on a cycle ergometer in order to match the physiological load achieved while walking on a treadmill. Heart rate data were recorded using a validated (Giles, Draper, & Neil, 2016) V800 Polar heart rate monitor and a Polar H7 chest strap (Polar OY, Finland). During the second cycling trial, the metabolic load between walking and cycling was normalised by matching oxygen consumption (VO_2 matched; equations are displayed below) using the following equations proposed by the American College of Sports Medicine (Glass & Dwyer, 2007). Subsequently, the equations were then readjusted to calculate equivalent work rate for children to perform another cycling trial.

Walking

VO_2 (ml.kg^{-1}.min^{-1}) = (0.1 x speed) + (1.8 x speed x grade) + 3.5

Cycling

VO_2 (ml.kg^{-1}.min^{-1}) = 1.8 x (work rate/mass in kg) + 7

Before each trial, an acclimatisation period was used where participants had the chance to walk or cycle for at least five minutes. The acclimatisation period was ended once children were able to walk on a treadmill without holding the guard rails with their hands and verbally reported that they were walking comfortably on the equipment. For cycling, the acclimatisation period ended once the child was able to maintain a cycling pace of 65 revolutions per minute at a power output of 52 watts on a cycle ergometer and reported that they were comfortable with the equipment.

5.2.4 Walking

Prior to the walking trials, participants practised walking on an instrumented treadmill at a self-selected cadence. Subsequently, participants were asked to walk at their fastest walking speed on the treadmill. This walking trial started with a slow cadence and it was gradually increased to a point where the child would start running. Testing started once children reached their fastest walking cadence and lasted for approximately three minutes. Kinematic data were measured simultaneously with force plates on a fully instrumented dual-belt treadmill at 960 Hz (Bertec Corp, Columbus, OH, USA). Thirty-one spherical retro-reflective markers were bilaterally positioned on surface anatomical landmarks of the lower limbs, trunk and head: first and fifth metatarsal head, lateral and medial malleoli, right and left calcanei, lateral and medial femoral epicondyles, the greater trochanters, base of sacrum, anterior superior iliac spines, at the distal end of each clavicle, c7, proximal sternum, right and left occipital bone landmarks, right and left orbital bone landmarks. Four additional markers were placed on thighs and shanks to identify these segments.

5.2.5 Cycling

Participants performed two cycling trials and were instructed to maintain a pedalling rate of 65 revolutions per minute on a cycle ergometer. A metronome was set at 65 beats per minute to assist the participants in maintaining this target cadence. In addition, the cadence was closely monitored "online" by the experimenter, and instructions were given, so children were aware when their pedalling rate was lower or higher than the one that was previously instructed. Equally to walking trials, each cycling trial lasted for approximately three minutes. Kinematic data were collected using a ten-camera three-dimensional motion capture system at a sampling rate of 120 Hz. Pedal reaction forces were collected at 960 Hz using a custom-made instrumented force pedal (model 9251AQ01, Kistler, Winterthur, Switzerland). Eleven spherical retro-reflective markers were bilaterally positioned on anatomical landmarks of the right leg: first and fifth metatarsal head, lateral and medial malleoli, calcanei, lateral and medial femoral epicondyles, the greater trochanters, anterior superior iliac spines. Two additional markers were placed on the right thigh and right shank to identify these segments. Prior to each cycling trial, participants familiarised themselves with the equipment and practised cycling with the metronome. The order of the cycling trials, HR matched and VO_2 matched, was randomized. Each participant was fitted to the bike based on the recommendations of Grainger, Dodson, & Korff (2017).

5.2.6 Assessment of perceived effort

Participants reported their perceived effort during treadmill walking and both cycling trials, HR matched and VO_2 matched, using the Children's Effort Rating Table (CERT) proposed by Williams, Eston, & Furlong (1994). The CERT has been validated (Eston, Lamb, Bain, Williams, & Williams, 1994; Leung, Chung, & Leung, 2002) and recommended (Lambrick, Bertelsen, Eston, Stoner, & Faulkner, 2016) to assess perceived effort in children. This is a non-invasive and consistent method that involves a 10-point scale to assess perceived effort in children (see appendix XVI). The protocol of the CERT is similar to the rating perceived exertion scales that were earlier proposed by Borg (1973, 1982) for adults. The CERT was explained to children prior to the walking and cycling trials. Children were instructed on how to report perceived effort that they have experienced during cycling trials. Instructions were given specifically regarding the regions that they were likely to experience effort, i.e. muscles in the calf and thighs. Finally, at the end of each trial, the child was asked to indicate the way they physically perceived the activity that they performed. Possible responses ranged from 1 (very, very easy) to 10 (so hard I am going to stop).

5.2.7 Assessment of pain

The way children perceived walking and both cycling trials regarding comfort was self-reported using a visual analog scale. This method consists of a 10 centimetres horizontal line, without any number, where children indicated whether they experienced discomfort and how uncomfortable the activity was by crossing this line with a pen (Varni, Thompson, & Hanson, 1987). In addition to the horizontal line, the scale also has facial expressions (Hockenberry, Rodgers, & Wilson, 2016) and texts on each side of the line indicating no discomfort and very uncomfortable (see appendix XVII). This method has been widely recommended for measuring pain or discomfort in children (Cohen et al., 2008; Garra et al., 2010; Huguet, Stinson, & McGrath, 2010; Stinson, Kavanagh, Yamada, Gill, & Stevens, 2006). Similarly to the procedures described for assessing perceived effort, children were also educated on how to respond to the question on the visual analog scale. Children were educated regarding the differences between pain and perceived effort that they might experience during cycling trials. Children were informed regarding regions in which they could be prone to experience pain, e.g. ankle and knee joints, and symptom differences when compared to perceived effort. As the cycle ergometer was individually set up for each child according to their anthropometry during cycling trials, pain or discomfort derived from the instrument itself was minimised. At the end of each trial, children were individually asked to indicate whether or not they experienced any discomfort during the activity. Children used a pen to mark a line over the horizontal line in the questionnaire to indicate how comfortable/uncomfortable the trial was. Discomfort was further analysed using a ruler over the horizontal line, where zero centimetres indicated no discomfort and 10 centimetres being very uncomfortable.

5.2.8 Data analysis

Cycling trials were digitised with Cortex-64 3.6.1.1315 64-bit (Motion Analysis, Santa Rosa, CA, USA) and exported for further computations. Right-sided data, from walking and cycling trials, were selected for analysis. Kinematic cycling data were filtered using a 2nd order Butterworth low pass filter with a cut-off frequency of 10 Hz. Kinetic cycling data were filtered using a 2nd order Butterworth low pass filter with a cut-off frequency of 20 Hz. Joint reaction forces and moments at the knee and ankle joints during cycling trials were estimated using inverse dynamics as described by Barratt, Martin, Elmer, & Korff (2016). All data from the cycling trials were analysed with a custom written script (see appendix XVIII) using MATLAB (Natick, MA, USA). The dependent variables considered to represent joint loading (Ericson & Nisell, 1986) were peak joint moments, shear (anterior-posterior) forces and compressive joint reaction forces at the knee and ankle joints. All dependent variables were average values across all available full revolutions.

For the walking trials, kinematic data were digitised and trimmed using Cortex. Kinetic data were filtered using a low pass fourth order Butterworth filter with a cut-off frequency of 6 Hz to remove noise (Shultz et al., 2014). All dependent variables relating to the walking trials were processed with Visual 3D software (C-Motion, Inc., Germantown, MD, USA) version 5. Reliability analyses were performed to obtain coefficients of variation (see appendix XIX). Ten consecutive gait cycles were used to calculate dependent variables from walking trials (Mills, Morrison, Lloyd, & Barrett, 2007; Neptune, Sasaki, & Kautz, 2008). From walking trials, dependent variables were calculated from right heel strike until right toe-off phase of each stride. Joint moments and reaction forces from cycling and walking trials, calculated through inverse dynamics, were normalised by dividing by the participant's body mass. Time normalisations were computed for each stride and 101 points were exported to represent equal intervals from 0 to 100%.

5.2.9 Statistical analysis

The assessment of the normality of the data was performed using the Shapiro-Wilk test. Descriptive statistics were used to report the following variables: body mass, stature, BMI, age, PAQ-C score and the prediction of age of peak height velocity (biological maturity). To test the hypothesis that peak joint moments, peak shear and peak compressive forces would be different between walking and HR matched cycling, a Hotelling's *t*-test was conducted. Another Hotelling's *t*-test was performed to test the hypothesis that peak joint moments, peak shear and peak compressive forces would be different between walking and VO_2 matched cycling. In case of significance, post-hoc paired *t*-tests with a Bonferroni correction were conducted. The Wilcoxon signed-rank test was used to compare pain and perceived effort scores between walking and HR matched cycling and also between walking and VO_2 matched cycling. Statistical analyses were performed on the statistical software SPSS (Statistical Package for the Social Sciences Inc., Chicago, IL, USA), version 25.

5.3 Results

5.3.1 Descriptive characteristics of participants and overall results

Three participants failed to maintain 65 revolutions per minute during the HR matched cycling trial and five participants failed to maintain this pace during the VO_2 matched cycling trial. These participants cycled consistently faster than 65 revolutions per minute, so their cycling data were not compared to their walking trials. An independent-samples t-test was performed to compare body mass, stature, BMI, age, PAQ-C score and APHV between excluded and included participants. Analysis yielded no significant differences in data from excluded participants regarding body mass 35.1 kg ($t(15)=-.675$, $p = 0.510$), stature 141 centimetres ($t(15)=-.320$, $p = 0.753$), BMI 17.3 kg/m^2 ($t(15)=-.788$, $p = 0.443$), age 10.3 years ($t(15)=-.394$, $p = 0.699$), PAQ-C score 2.9 ($t(15)=-.583$, $p = 0.568$) and APHV -2.5 years ($t(15)=-.562$, $p = 0.582$). Characteristics of participants included in the study can be found in table 5.1. The mean PA score was

3.1 (SD=0.7), according to the PAQ-C. The prediction of the biological maturity was -2.2 years from the maximum velocity in stature growth during adolescence.

Table 5.1 Participant characteristics.

	Mean	**SD**
Body mass (kg)	38.3	12.6
Stature (m)	1.43	0.1
BMI (kg/m^2)	18.3	3.1
Age (year)	10.5	1.6
PAQ-C score (1 to 5)	3.1	0.7
APHV (year)	-2.2	1.5

APHV: Prediction of Age of Peak Height Velocity

The mean walking speed achieved on the treadmill during walking trials was 1.43 metres per second (SD=0.3). The mean work rate achieved during cycling trials is described in table 5.2. Average work rate during the HR matched cycling trial was 46.0W (SD=15.9) and 23.6W (SD=6.9) during the VO_2 matched cycling trial. Physiological demand values from the HR matched cycling trial was 126.6 beats per minute (SD=12.8) and 12.1 ml.kg^{-1}.min^{-1} (SD=1.6) from the VO_2 matched cycling trial.

Table 5.2 Description of average work rate from cycling trials (in watts).

	Cycling (HR matched)		Cycling (VO_2 matched)	
	Mean	**SD**	**Mean**	**SD**
Work rate	46.0	15.9	23.6	6.9

n=14

The Hotelling's t-test for differences between HR matched walking and cycling was significant ($F(9,5)=129.14$, $p<0.001$). Similarly, results from the Hotelling's t-test testing the difference between VO_2 matched walking and cycling were also significant ($F(9,2)=61.201$, $p=0.016$). Thus, the hypothesis of whether or not peak joint moments, peak shear and peak compressive forces would be different between walking and cycling was accepted.

5.3.2 Knee and ankle joint moments

Results revealed that ankle plantarflexion peak moments were greater during walking than during HR matched cycling (Table 5.3 and figure 5.1; $p<0.001$). Results also revealed that ankle plantarflexion peak moments were smaller during VO_2 matched cycling compared to walking (Table 5.4 and figure 5.1; $p<0.001$). There were no significant differences in knee extension and knee flexion moments between cycling and walking ($p=0.616$ and $p=0.801$, respectively).

Table 5.3 Mean, SD, peak moment (Nm/kg) and mean difference with 95% CI in peak moment between walking and cycling physiologically matched using heart rate.

	Walking		Cycling (HR matched)						
	Mean	**SD**	**Mean**	**SD**	**Mean difference**	**95% CI**	**t**	**df**	***p*-value**
Knee extension	0.19	0.16	0.23	0.09	-0.024	(-0.13 to -0.08)	-0.51	13	0.616
Knee flexion	-0.17	0.05	-0.17	0.06	-0.006	(-0.05 to -0.04)	-0.26	13	0.801
Ankle plantarflexion	1.14	0.24	0.35	0.09	0.803	(0.64 to 0.97)	10.50	13	**<0.001**

Using the heart rate equation to match physiological demands from walking trials n=14. Bold indicates $p<0.050$.

Table 5.4 Mean, SD, peak moment (Nm/kg) and mean difference with 95% CI in peak moment between walking and cycling physiologically matched using VO_2.

	Walking		Cycling (VO_2 matched)						
	Mean	**SD**	**Mean**	**SD**	**Mean difference**	**95% CI**	**t**	**df**	***p*-value**
Knee extension	0.19	0.16	0.14	0.13	0.056	(-0.09 to 0.20)	0.87	11	0.405
Knee flexion	-0.17	0.05	-0.16	0.09	-0.021	(-0.08 to 0.04)	-0.79	11	0.444
Ankle plantarflexion	1.14	0.24	0.31	0.11	0.862	(0.70 to 1.04)	10.86	11	**<0.001**

Using American College of Sports Medicine equations n=12. Bold indicates $p<0.050$.

Table 5.5 Mean, SD, peak shear force (N/kg) and mean difference with 95% CI between walking and cycling physiologically matched using heart rate.

	Walking		Cycling (HR matched)						
	Mean	SD	Mean	SD	Mean difference	95% CI	t	df	*p*-value
Knee anterior	1.12	0.37	0.63	0.27	0.576	(0.31 to 0.85)	4.60	13	**<0.001**
Knee posterior	-1.39	0.41	-0.70	0.30	-0.709	(-1.04 to -0.39)	-4.71	13	**<0.001**
Ankle anterior	1.59	0.34	0.80	0.27	0.869	(0.64 to 1.09)	8.37	13	**<0.001**
Ankle posterior	-1.77	0.49	-0.80	0.31	-0.980	(-1.37 to -0.59)	-5.37	13	**<0.001**

Using the heart rate equation to match physiological demands from walking trials n=14. Bold indicates p<0.050.

Table 5.6 Mean, SD, peak shear force (N/kg) and mean difference with 95% CI between walking and cycling physiologically matched using VO_2.

	Walking		Cycling (VO_2 matched)						
	Mean	SD	Mean	SD	Mean difference	95% CI	t	df	*p*-value
Knee anterior	1.12	0.37	0.32	0.21	0.820	(0.48 to 1.16)	5.34	11	**<0.001**
Knee posterior	-1.39	0.41	-0.77	0.27	-0.688	(-1.05 to -0.33)	-4.25	11	**0.001**
Ankle anterior	1.59	0.34	0.50	0.27	1.092	(0.77 to 1.42)	7.25	11	**<0.001**
Ankle posterior	-1.77	0.49	-0.87	0.29	-1.011	(-1.43 to -0.59)	-5.32	11	**<0.001**

Using American College of Sports Medicine equations n=12. Bold indicates p<0.050.

Table 5.7 Mean, SD, peak compressive force (N/kg) and mean difference with 95% CI in peak moment between walking and both cycling trials.

	Walking		Cycling (HR matched)						
	Mean	**SD**	**Mean**	**SD**	**Mean difference**	**95% CI**	**t**	**df**	***p*-value**
Knee	-11.94	1.79	-3.33	0.99	-8.859	(-9.84 to -7.88)	-19.59	13	**<0.001**
Ankle	-12.70	1.74	-3.90	1.01	-9.038	(-9.95 to -8.13)	-21.43	13	**<0.001**

	Walking		Cycling (VO_2 matched)						
	Mean	**SD**	**Mean**	**SD**	**Mean difference**	**95% CI**	**t**	**df**	***p*-value**
Knee	-11.94	1.79	-2.61	0.71	-9.474	(-10.79 to -8.16)	-15.85	11	**<0.001**
Ankle	-12.70	1.74	-3.24	0.93	-9.575	(-10.96 to -8.19)	-15.26	11	**<0.001**

Using American College of Sports Medicine equations n=12. Using the heart rate equation to match physiological demands from walking trials n=14. Bold indicates p<0.050

Table 5.8 Median and interquartile range (IQR) for perceived effort and pain between walking and both cycling trials.

	Walking		Cycling (HR matched)		
	Median	**IQR**	**Median**	**IQR**	***p*-value**
Effort score	2.00	3.00	4.00	4.00	**0.011**
Pain score	0.00	0.00	0.00	3.00	0.141
	Walking		**Cycling (VO_2 matched)**		
	Median	**IQR**	**Median**	**IQR**	***p*-value**
Effort score	2.00	3.00	3.00	3.00	0.067
Pain score	0.00	0.00	0.00	2.00	0.461

Effort score according to the CERT = Children's Effort Rating Table (score range: 1 to 10). Bold indicates p<0.050.
Pain score according to the VAS = Visual Analog Scale (score range 0 to 10). n = 12.

5.3.3 Knee and ankle shear forces

Table 5.5 and figure 5.2 show peak anterior and posterior shear forces on knees and ankles during walking and HR matched cycling. Shear peak anterior forces at the knee and ankle were significantly greater during walking than during cycling ($p<0.001$). Similarly, shear peak posterior forces at the knee and ankle were greater during walking than during cycling ($p<0.001$). Peak anterior and posterior shear forces on knees and ankles were also greater during walking than in VO_2 matched cycling. Table 5.6 shows that shear peak anterior forces for VO_2 matched cycling were lower at knee and at the ankle than during walking ($p<0.001$). Shear peak posterior forces during VO_2 matched cycling were also lower, at the knee and ankle ($p<0.001$), than during walking.

5.3.4 Knee and ankle compressive forces

Table 5.7 and figure 5.3 describe compressive peak forces on the knees and ankles of children during walking and HR matched and VO_2 matched cycling trials. Results revealed that compressive peak forces were greater on the knees and ankles during walking than during cycling ($p <0.001$). Compressive peak forces in the knees and ankles were significantly larger in walking than during VO_2 matched cycling ($p <0.001$).

5.3.5 Perceived exertion and pain

Results from perceived exertion and pain analyses can be found in table 5.8. Children reported less effort during treadmill walking than HR matched cycling ($p=0.011$). No significant difference was found regarding pain between treadmill walking and HR matched cycling ($p=0.141$). Analyses also revealed no differences between walking on a treadmill and VO_2 matched cycling for perceived effort ($p=0.067$) and pain scores ($p=0.461$).

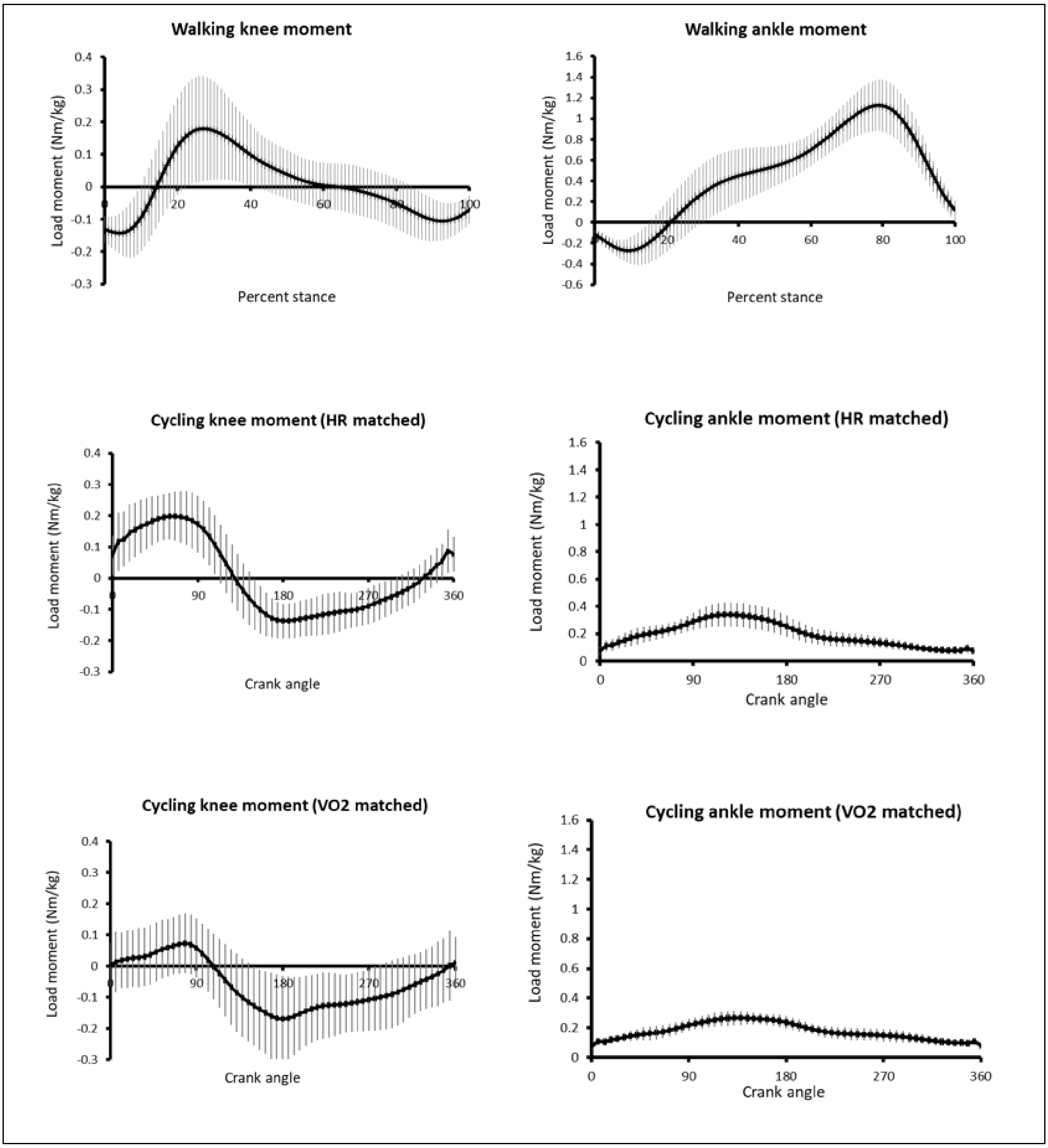


Figure 5.1 Moments of force (Nm/kg) for walking (from heel strike to toe-off) and cycling trials.

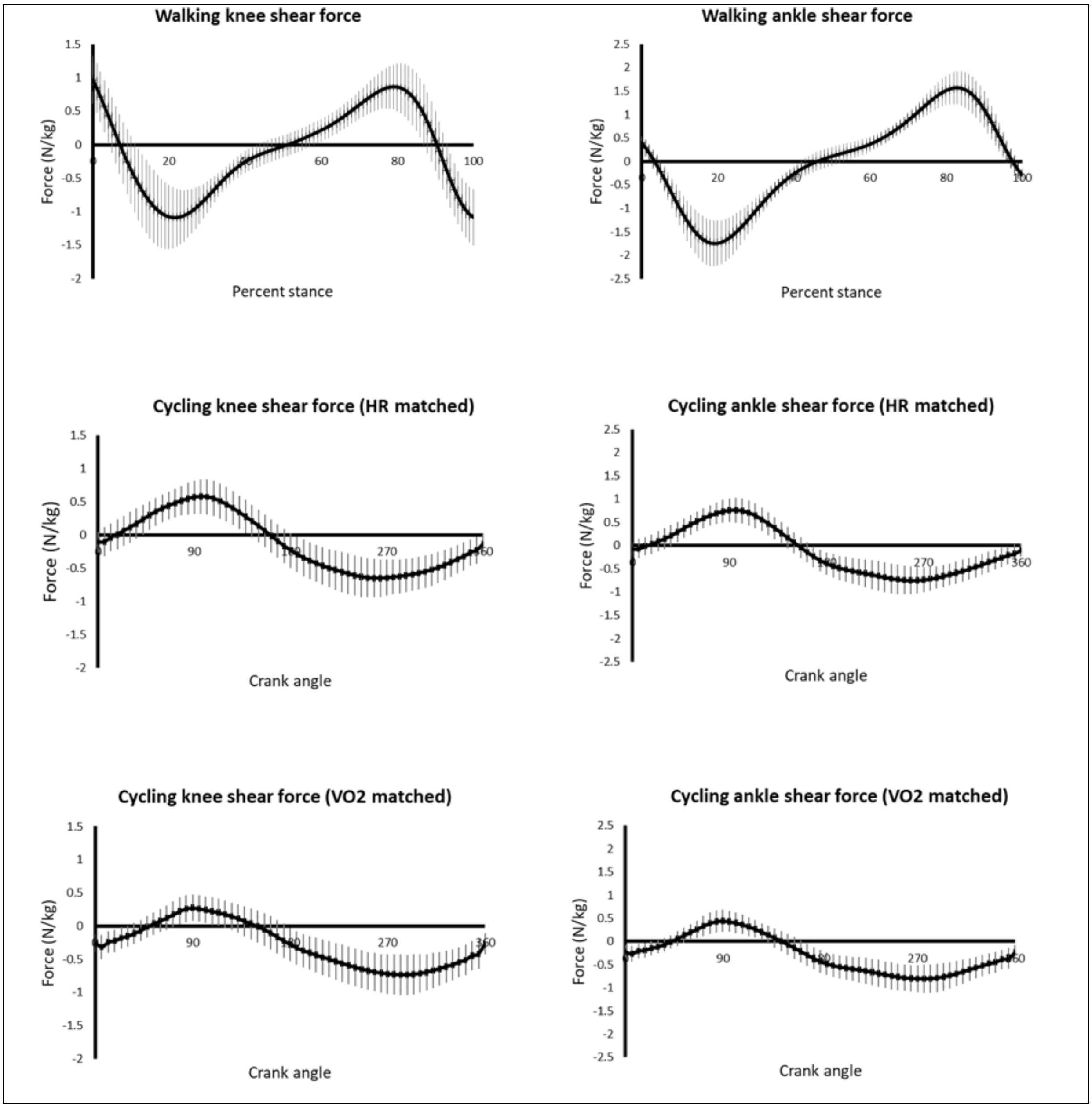


Figure 5.2 Shear forces (N/kg) for walking (from heel strike to toe-off) and cycling trials. Positive values show anterior and negative values show posterior forces.

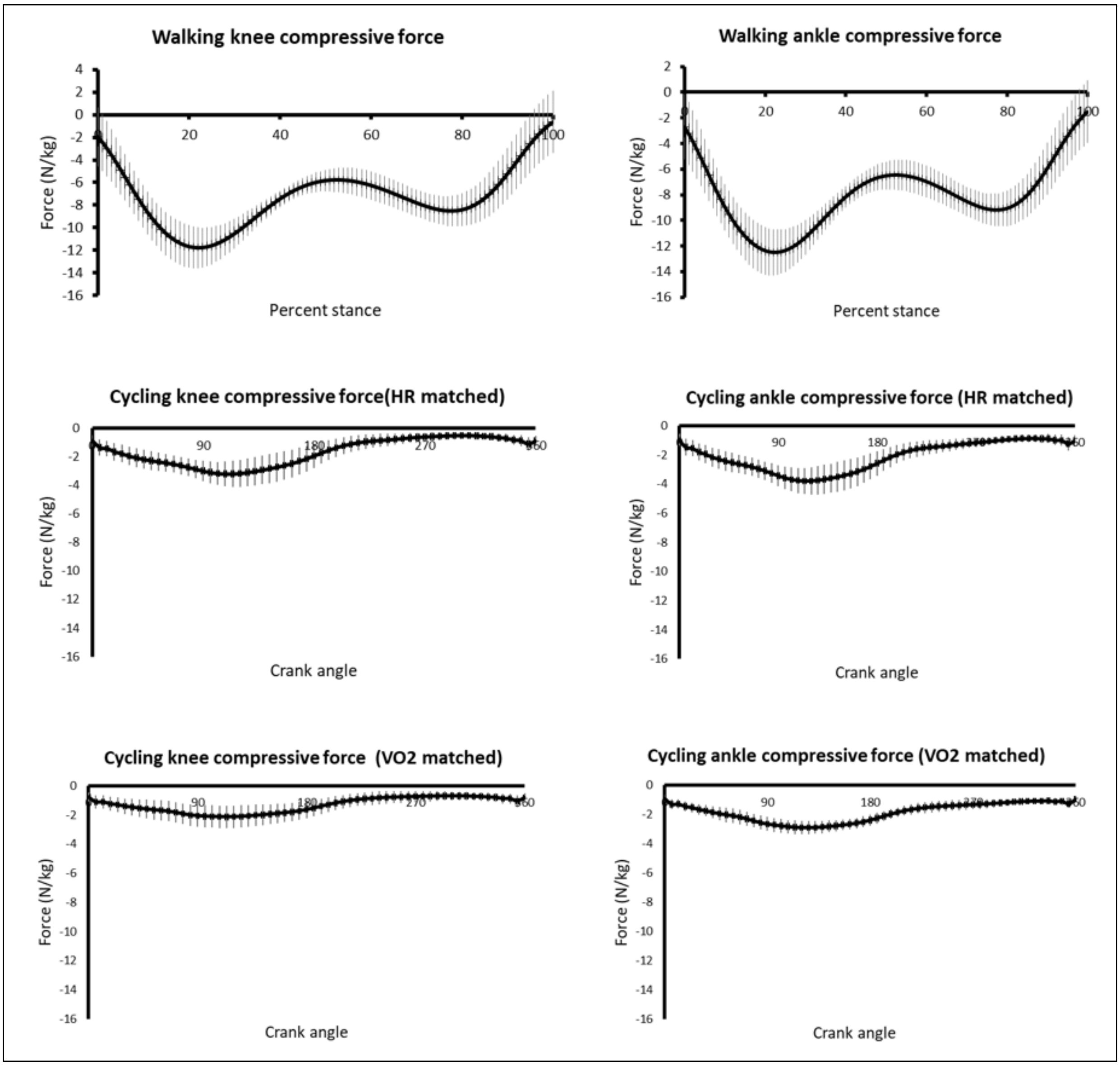


Figure 5.3 Compressive forces (N/kg) for walking (from heel strike to toe-off) and cycling trials.

5.4 Discussion

The purpose of this study was to investigate differences in joint loading between walking and cycling in children, but at similar physiological intensities in order to compare activities that provide equivalent cardiovascular benefit. We used validated methods to assess perceived pain and effort from participants while performing these activities. We also used two different methods to match physiological intensities from walking and cycling in order to be able to draw robust conclusions assuming the results would be independent of the method used to match physiological load. We hypothesized that the dependent joint loading variables would be greater during walking (weight bearing activity) than during cycling (non-weight bearing activity). Our results showed that during cycling, ankle moments, as well as shear and compressive forces in knee and ankle joints, were smaller compared to walking independent of how physiological load was matched between the two tasks. Additionally, at similar intensities, children reported less effort to walk on the treadmill than to perform HR matched cycling. No statistical difference was detected in perceived pain between walking and both cycling conditions.

The systematic search performed in the chapter two of the present thesis indicated that no study compared joint loading or pain between two different activities in children. Two studies that aimed to investigate weight bearing activities in children were identified in the systematic search (Lerner et al., 2016; Riddiford-Harland et al., 2016). Lerner et al. (2016) aimed to examine how OB and duration of walking could affect loading in the knees of children. The authors found that PA duration was associated with increased joint loading. During treadmill walking, medial compartment loading was 1.78 times greater in participants with OB than in healthy-weight participants. Body fat percentage and tibiofemoral medial-lateral force distribution had a strong linear relationship ($r^2 = 0.79$; $p < 0.001$). Riddiford-Harland et al. (2016) aimed to examine how a weight bearing PA programme could affect the foot structure and change plantar pressure generated in children who were OW or obese. The authors found that a weight bearing PA programme did not alter the magnitude of peak plantar pressure distributions generated during the walking assessment.

Comprehending joint loading differences generated by both activities investigated in the present study is a useful first step to differentiate PA recommendations in children.

More specifically for PA recommendations for particular paediatric populations such as children with OW and OB. For instance, children who are more prone to lower limb injury or pain may be better advised to achieve their PA recommendations by means of non-weight bearing activities as they can generate less loading in joints while achieving similar physiological intensities. Evidence has shown that a certain amount of joint and bone loading is beneficial for healthy bone development as it can contribute to optimising bone mass in children (Landry & Driscoll, 2012). However, OW and OB have been associated with musculoskeletal pain in children (Paulis et al., 2014). Thus, there may be situations in which excessive or increased physiological forces in the joints can lead to pain while practising PA. In this case, cycling might be an alternative option as it can evoke similar physiological benefits in children, such as protection against excess body fat (Bere et al., 2011), improved cardiorespiratory fitness (Maher et al., 2012) or improved physical abilities such as agility, balance and reaction response (Lirgg et al., 2018).

A limitation of this study is that analyses were not stratified according to children's body weight. This was not possible due to a very small number of children with OW and OB. In the present study, the external load was adjusted using a fast walking pace as a reference for cycling trials. Thus, it is unknown whether the magnitude of the results could have been different if children were asked to perform HR matched and/or VO_2 matched cycling trials and use these tasks as work load references for walking trials. In order to confirm joint loading magnitude differences between walking and cycling further studies should investigate forces and moments using external loads from cycling as a reference for walking. Another limitation of this study was that the joint reaction forces derived from inverse dynamics do not consider individual muscle forces or antagonistic contraction surrounding ankle and knee joints.

Thus, further research should specifically investigate the benefits of non-weight bearing activities in those populations that are predisposed to joint injuries taking individual muscle contributions into consideration. Our results provide a useful basis for future research to assess these speculative links explicitly, specifically with respect to children with OW and OB.

A secondary purpose of this study was to assess the difference in pain and perceived effort experienced between cycling and walking. *Children were informed about the difference in symptoms between pain and perceived effort, in order for the two not to be confounded.* There is a rationale for assessing pain, in addition to joint loading, as evidence shows that there OW and OB have been associated with musculoskeletal pain in childhood (Paulis et al., 2014). This issue can prevent children from successfully engaging in recommended PA (Department of Health Physical Activity Health Improvement and Protection, 2011). Thus, Stovitz et al. (2008) urged that professionals supervising PA programmes should take into account that children might experience pain when practising PA. Esposito et al. (2013) later concluded that in order to pursue healthy growth and/or maintain healthy weight children should not only be able to exercise, but also to practice recommended PA without pain. Thus, in addition to joint loading, perceived pain and effort were assessed in the present investigation. In our results, children reported that HR matched cycling was physically more demanding than walking on a treadmill. No statistical difference was found for perceived effort between VO_2 matched cycling and walking on a treadmill. A possible explanation for children reporting more effort only while performing HR matched cycling, might be related to the difference in work rate between both cycling trials. During HR matched, cycling children cycled at a work rate of 46.0 W whilst during VO_2 matched cycling they kept an average work rate of 23.6 W. No statistical difference was found with regards to perceived pain between walking and both cycling trials. Evidence in the literature indicates that musculoskeletal pain seems to be prevalent among OW children (Paulis et al., 2014). Nevertheless, the fact that children reported demanding more effort to perform cycling trials than walking should be considered. It is possible that adherence to cycling, as a form of regular activity, might be reduced among children, as this activity seems to demand more effort than walking. Further studies should consider this issue whilst investigating weight bearing and non-weight bearing activities. The present study did not stratify the sample according to their body weight as it included a very small number of children with OW and OB. This might be a reason for our analysis demonstrating no difference regarding pain. Another limitation related to these analyses is that the way children were instructed to report perceived effort and pain might have influenced them to report pain either in lower limbs only or specific joints such as ankles and knees. In this study, children were advised on the regions in which they would be more likely to experience effort, i.e.

muscles in the calf and thighs. This might have led them to focus exclusively on effort perceived in these regions and not on others. Children were informed regarding regions in which they could be prone to experience pain, e.g. ankle and knee joints. This could also have led children to focus on these regions only. Thus, these findings should be seen as initial insights on the way children perceive walking and cycling while performing them at similar intensities. Future research should consider the assessment of pain and perceived effort in children with OW and OB when estimating joint loading.

Results from the present chapter show that cycling, at matched intensities, generates less joint loading than walking. Our results show that no difference was found in pain while children performed both activities. They thereby provide a biomechanical basis to advocate non-weight bearing PA recommendations where excessive joint loading is to be avoided.

CHAPTER 6. THE FEASIBILITY OF CYCLING AS A FORM OF ACTIVE COMMUTING AMONG CHILDREN FROM A PARENTAL PERSPECTIVE: A QUALITATIVE STUDY

6.1 Introduction

Results from chapter 5 indicate that cycling can generate less joint loading than walking, while being performed at a similar intensity. However, the hypothesis that increased joint loading during walking was associated with increased lower limb pain was not supported, as there was no difference in lower limb pain experienced between cycling and walking. However, although not tested in this thesis, it is possible that increases in joint loading may lead to pain when performing weight bearing activities at a high intensity. Further, it is possible that weight bearing activities may generate sufficiently high levels of joint loading to cause pain, when performed by children with excess body weight.

If weight bearing activities such as walking generate an increase in joint loading and subsequently an increase in pain, cycling may be a more acceptable type of PA than weight bearing activities for some children. However, participation in cycling in England is low (Voss & Sandercock, 2010). Active commuting has been recommended as a potential way to increase children's engagement in PA (Wilkie et al., 2016). An understanding of the barriers to active commuting by bicycle is required in order to form recommendations on how to increase participation in cycling in the UK. The systematic search conducted in chapter two identified two studies that examined barriers and facilitators of active commuting in children using a qualitative approach (Ahlport et al., 2008; Sisson et al., 2006). These studies were conducted in the United States.

Thus, we have identified a lack of studies exploring the feasibility of cycling as a form of active commuting. Specifically, in England, there is a paucity of studies investigating parental perspectives regarding their children actively commuting to school by bicycle. The use of qualitative methods is required to understand the feasibility of cycling as a form of active commuting. Using qualitative methods to explore this topic allows us to gain in-depth understanding regarding children using bicycles to actively commute. Qualitative methods provide tools to examine the topic in a close way, so that barriers preventing children from cycling can be understood while interviewing parents. This is because evidence in the literature reports that parents are the decision-makers (Lee & Tudor-Locke, 2005) as they play an important role in a child's PA through socialisation and other ways (Welk, Wood, & Morss, 2003). Evidence reports that parents influence their children's attitudes and interests both directly and indirectly; levels of PA of a child, for instance, can be shaped via socialisation (Welk et al., 2003). Therefore, the aim of the present study was to explore the barriers to children cycling as a means of active commuting.

6.2 Methodology

6.2.1 Study approach

The present study used qualitative methods for collecting and analysing data. Qualitative research is described as a type of investigation that is carried out to explore problems through collecting information, image or text data, that expresses participants' perspectives on the research problem being investigated (Clark & Creswell, 2014). Overall, qualitative research uses a series of specific strategies to collect, analyse and report data in order to answer questions. This occurs by exploring points of views from participants (Clark & Creswell, 2014). Although the present thesis has a deductive theoretical drive, i.e. where the major goal is to test, the present chapter has an inductive theoretical drive, i.e. it has an overall goal of discovering issues to understand a phenomenon (Morse, 2003). Qualitative researchers must take into account the following aspects: 1) ethical challenges and issues for collecting information from participants either via telephone or face-to-face interviews at participants' workplaces or homes; 2) select a number of participants and/or data collection sites to increase understanding of a phenomenon; 3) adopt procedures to collect data that allow participants to produce their personal perspectives and; 4) collect data using texts or images to generate abundant and in-depth detail for further understanding (Clark & Creswell, 2014). Qualitative methods can be used to answer a variety of different questions. Overall, research questions will fit into one of the four following categories: *strategic*, *contextual*, *evaluative* and *diagnostic*. The diagnostic perspective examines reasons or causes regarding a context, i.e. why certain decisions are being taken or why this behaviour is being adopted (Ritchie & Spencer, 1994). Thus, the present investigation had a diagnostic perspective.

6.2.2 Participant identification

The study took place in the London Borough of Hillingdon, England. Eligibility criteria to take part in the present investigation were: being a father or a mother of a student, aged 8-12 years, attending a primary or secondary school. A combination of convenience sampling and snowball sampling (Goodman, 1961) was used to identify participants in the present study. Convenience sampling is a sampling technique where participants are accessible (Given, 2008). Snowball sampling refers to a technique where current participants suggest acquaintances as potential participants (Goodman, 1961).

Parents of children who took part in the study presented in chapter four, were asked to consent to being contacted about participating in future studies. Fifty parents who agreed to be contacted were sent e-mails inviting them to participate in the present study. E-mails with full description about the present study (see appendix XX) were sent to parents. E-mails were sent for a second time to parents that did not respond to the first e-mail with a description of the study and an invitation to participate. Of the parents who received e-mails, six agreed to participate. These parents were then asked if they had acquaintances. Parents who agreed to participate were sent further emails to identify a convenient day and time for them to be interviewed. Ethical approval (see appendix XXI) was obtained from the College of Health and Life Sciences Research Ethics Committee at Brunel University London (reference number 7250-MHR-Jul/2017 – 7949-1). Participants provided verbal informed consent over the telephone prior to data collection. Data collection occurred in September and October of 2017.

When determining sample size, the present study took into account items that can influence information power. The principle of data saturation was not used in the present study as this assumption does not offer preliminary guidance (Malterud, Siersma, & Guassora, 2016). The concept *information power* was proposed by Malterud et al. (2016), where the authors developed a model to determine sample size in qualitative research. According to the conceptual model, the following items must be taken into account to achieve information power when using qualitative research methods: *study aim*, *sample specificity*, *use of established theory*, *quality of dialogue* and lastly *analysis strategy*. Essentially, the authors advised that these factors can influence the information power of a sample in different ways. First, to achieve information power through *study aim*, the researcher must carefully distinguish whether or not the study has a narrow or broad aim. The present study has a narrow aim, i.e. to explore the feasibility of cycling as a form of active commuting among children. Thus, a large sample was not essential as the study does not aim to cover a comprehensive topic. Second, *sample specificity* relates to the fact that information power depends, also, on the background of participants, i.e. their knowledge depth on the topic and their experience with it. Parents were interviewed in the present study as they have a considerably large amount of experience regarding the topic being investigated. Thus, a small sample size is enough to achieve information power in this scenario. A third aspect takes into account whether or not the study has an *established theory,* i.e. whether or not there is a theoretical background supporting that study. The topic being investigated in the present study has a theoretical background that indicates that parental perspective (Lee & Tudor-Locke, 2005; Wright et al., 2010) and local policies (Sisson et al., 2006) seem to influence active commuting in children. Thus, a small sample size is suitable to achieve information power. The fourth, *quality of dialogue*, can contribute to information power of a study by providing substantial and transparent communication between the interviewer and participants. The interviews conducted in the present study were clear and efficient between the researcher and participants. Thus, a smaller sample size was necessary when compared to studies where the communication between interviewer and participants are weak and vague. Lastly, regarding the *analysis strategy*, the present study used the Framework approach to analyse data. This means that the strategy used to analyse data in the present study involves a series of steps that allow us to understand whether or not we have enough data from our sample to continue working on an analytical Framework. For instance, the use of this approach allows interplay when performing data collection, data analysis and the development of themes (Gale, Heath, Cameron, Rashid, & Redwood, 2013).

In the present study, eighteen parents (eight males) were interviewed. These parents reside in different areas of West London. The fact that parents reside in different regions, lived in different distances from schools, in addition to the fact that some parents themselves were cyclists and others were not, contributed to form a sample that could provide different perspectives on the feasibility of cycling for children.

6.2.3 Development of the topic guide

First, deductive questions related to active commuting and potential variables related to this behaviour in children were developed. These questions were compared to data (see appendix XXII). Meetings were held between the PhD candidate, supervisor and research advisor. We found that, according to the specific body of the literature, high parental concern was quantitatively associated with active commuting in children. Kerr et al. (2006) reported that children of parents who had little concerns about them actively commuting were five times more likely to maintain this behaviour. Thus, we decided that *parental perspective* on active commuting should be included in the interview topic guide. We included the following questions: *What are the reasons for choosing this way (walking, bus, car or cycling) to get to school? Why does/doesn't your child cycle to school? What would have to change for your child to cycle to school? How realistic is it for your child to cycle to school? Do you think there are advantages/disadvantages to cycling to school? Do you have anything else you want to say about using a bicycle to get to school?* Parental perspective at the *environment* level was included in the topic guide as parental concern has been related to safety issues and traffic of vehicles (Kerr et al., 2006). Also, urban design has been reported in a qualitative study on parental perceptions regarding where their children play (Veitch, Bagley, Ball, & Salmon, 2006). These factors provided insights for asking about parental views on this area. The following questions were included in the interview topic guide: *Do you think it is safe for your child to walk alone outside? What would be/are your greatest concerns about your child cycling to school? Does your child's school offer a suitable place to keep bicycles?* The *social environment* section emerged when developing the topic guide after reading evidence where it was reported that little is known about the influence of social environment factors on active commuting in children (Davison et al., 2008). Additionally, a study aiming to investigate social factors in children has been advised by Kerr et al. (2006), which corroborated our decision to include this area of interest. The following question related to the social environment of a child was added to the interview topic guide: *Does your child go to school with friends?* Lastly, a section with questions related to the *individual* was added to the topic guide. The following questions related to the individuality of the child were added to the interview topic guide: *How does your child usually go to school? What would your child's preferred method of getting to school be?* Prior to data collection, a few pilot interviews were conducted with colleagues with the intent of refining the topic guide and improving the researcher's interview skills. The questions that were included in the final topic guide can be seen in appendix XXIII.

6.2.4 Data collection

Initially, it was intended that parents would be interviewed in the school setting, right after leaving their children or before picking them up at school. However, it was acknowledged that collecting data from parents through face-to-face interviews would not be feasible due to the lack of time from parents. After talking to parents about their schedule, it was decided that interviews would work better if conducted via telephone. Telephone interviews were first used for quantitative surveys and more recently this method started being used more frequently in qualitative research (Given, 2008). Similarly to any other research method, using the telephone to perform interviews has advantages and disadvantages. For instance, it is possible that the use of telephones to interview participants may decrease rapport and result in distortion of communication (Novick, 2008). Another limitation of using the telephone for interviews is that the researcher does not have the opportunity to create an optimal ambience for the interview, i.e. setting up a place where participants feel comfortable (Given, 2008). On the other hand, telephone interviewing has advantages when compared to the face-to-face interview method. For instance, the costs for administering this method are significantly lower when contrasted to face-to-face interviews (Given, 2008; Oltmann, 2016). Also, it is possible to obtain rich data over the telephone as free-flowing conversations can occur (Given, 2008). This is due to the fact that participants can choose a suitable time and place to talk over the phone. Participants can talk more honestly and openly on certain topics as using the telephone can allow anonymity (Given, 2008). The present research protocol for performing telephone interviews took into account aspects proposed by Burke & Miller (2001) (see table 6.2). Briefly, Burke & Miller (2001) present insights regarding telephone interviews in three categories: *before the interview*, *during the interview* and *after the interview*. In the present study, before the interviews, the PhD researcher identified himself to parents, this included introducing the university where the research project was being developed as well as the sponsor of the research. Information regarding how data would be used was also explained to parents before the interview. During the interviews, the participant was allowed to talk freely while answering questions regarding the topic. Questions were asked with exact wording, following the order that the questions are presented in the interview guide. After the interviews, data from each interview were immediately prepared for data analyses, i.e. transcriptions of interviews took place, in order to preserve integrity of the research (Burke & Miller, 2001).

Table 6.1 Guidelines for performing telephone interviews in qualitative research. Adapted from the work of Burke & Miller (2001).

Before the interview	During the interview	After the interview
Pre-testing the interview protocol	Identifying appropriate interviewer style	Revisiting the collected data for accuracy
Communicating with potential participants	Getting the participant to talk freely	Preparing the data for analysis
Determining audio taping techniques	Creating different types of questions	Allotting ample time for data analysis
Pre-determining data analysis needs and logistics of gathering data	Giving useful feedback to participants, without distorting potential data	
Scheduling each of the interviews	Considering interview length concerns	
Introducing yourself in the call		
Informing participants of confidentiality		
Identifying necessary form of note-taking		
Communicating whether and/or how the results will be shared		

Thus, based on evidence in the literature, it became clear that using the telephone to collect data would not decrease data quality. Some parents that were interviewed had let their children take part in a previous study of the present thesis (chapter four). This can increase parental trust in the legitimacy of the research project. Thus, it is believed that parents were willing and comfortable to discuss the topic over the telephone. All the interviews were directly scheduled with parents. Pseudonyms were used to replace names of participants, preserve participants anonymity and data confidentiality. Semi-structured interviews were conducted and recorded over the telephone at times and days suggested by parents of children. Parents were asked to report their children’s attitude towards cycling and PA outside the school in general. Additionally, during the interviews, conversations on general PA and active commuting in children were allowed to create a natural and friendly environment between the interviewer and parents. According to the interview guide, each interview followed 12 central questions and the mean length of all interviews was 22 minutes and 05 seconds (SD 9 min 21 s). Dialogues during the interviews were audio recorded using a Dictaphone.

6.2.5 Data management and analysis

To preserve anonymity and confidential data from participants, personal information was not included in the transcripts. The Framework approach was used to analyse the data obtained from interviews (Ritchie & Spencer, 1994). This approach is an analytical process that involves different stages. During these stages, it is possible to revise ideas due to its analytical procedures. Essentially, the Framework approach involves sifting, mapping and organising collected data according to main problems and themes (Ritchie & Spencer, 1994). The systematic process of the Framework approach is organised into five different stages: *familiarisation*, *identifying a thematic framework*, *indexing*, *charting* and lastly *mapping and interpretation* (Ritchie & Spencer, 1994). More information on each stage of the approach used in the present study is presented below.

Ritchie & Spencer (1994) explain that a key goal of qualitative data analyses is to detect information in order to understand a context or problem. In qualitative research, after detecting relevant knowledge regarding the material collected, data should be methodically analysed following a series of steps until findings can be comprehensively understood and presented. Some of the tasks that a researcher has to achieve in qualitative research are: defining concepts, mapping the range of domains, creating categories for behaviours and attitudes, associating experiences and behaviours, seeking for meaning and developing new concepts (Ritchie & Spencer, 1994). The Framework approach was developed to assist researchers in successfully performing these stages described. Figure 6.1 describes key components of the Framework approach (Ritchie & Spencer, 1994).

- **Grounded or generative**: it is heavily based in, and driven by, the original accounts and observations of the people it is about.
- **Dynamic**: it is open to change, addition and amendment throughout the analytic process.
- **Systematic**: it allows methodical treatment of all similar units of analysis.
- **Comprehensive**: it allows a full, and not partial or selective, review of the material collected.
- **Enables easy retrieval**: it allows access to, and retrieval of, the original textual material.
- **Allows between-and within-case analysis**: it enables comparisons between, and, associations within, cases to be made.
- **Accessible to others**: the analytic process, and the interpretations derived from it, can be viewed and judged by people other than the primary analyst.

Figure 6.1 Key components of the *Framework* approach. Adapted from the work of Ritchie & Spencer (1994).

Gale et al. (2013) introduced a step-by-step model with seven different stages. The idea was to use this model to support researchers conducting qualitative research and using the Framework approach. The present study used all stages in the model to analyse collected data (Gale et al., 2013). More detail on how each stage of the Framework approach was applied is described below.

- **Stage 1**: Transcription
- **Stage 2**: Familiarisation with the interview
- **Stage 3**: Coding
- **Stage 4**: Developing a working analytical Framework
- **Stage 5**: Applying the analytical Framework
- **Stage 6**: Charting data into the Framework matrix
- **Stage 7**: Interpreting the data

In the *first stage*, the audios from interviews that were separately recorded using a Dictaphone were transcribed verbatim. Data were transcribed on the same day that interviews took place by the same researcher who conducted the interviews and analysis. Gale et al. (2013) advise that the transcription process can be a favourable opportunity for the researcher to engage even more with the collected material. For this reason, all transcriptions were performed by the PhD candidate. With the purpose of illustrating this stage, a random page from one of the interviews can be found in appendix XXIV. In the *second stage*, the researcher had the opportunity to get familiar with the interviews. This was achieved by reading all the interviews more than once. This stage allowed full comprehension of dialogues between the interviewer and participants; in case any ambiguity was found. Also, audio files from interviews were listened to several times while examining and reading the transcripts. The goal was to ensure that the researcher achieved full understanding of dialogues.

In the *third stage*, after the familiarisation stage was completed, the researcher read all transcriptions line by line with the intent to write explanations or labels. These notes eventually became codes. Codes represent what the research team understood in answers from parents. As the present study is an inductive study, an 'open coding' technique was adopted (Gale et al., 2013). The open coding technique allows anything to be coded as it can become an important piece of information to understand a problem (Gale et al., 2013). Essentially, a code can be attributed to anything that an interviewee reports, such as behaviours, emotions, values and beliefs, for instance. The ultimate aim of coding is to categorise all data so that systematic comparisons with other materials collected can be performed. A multidisciplinary team was involved in the coding stage. The first five interviews were independently coded by the PhD candidate and two other researchers from different specialties. This method allows carrying out the coding stage while using different standpoints, which ultimately avoids that a single perspective is followed (Gale et al., 2013). After listening to five interviews and reading these five transcripts, 94 preliminary codes were identified. The codes generated from this stage can be found in appendix XXV.

In the *fourth stage*, where the development of a working analytical Framework took place, the PhD researcher, his supervisor and a research advisor held several meetings to discuss and compare codes that were identified after examining the first five transcripts. The researchers discussed the labels until agreements were made regarding the sets of codes that would then be further applied to the following transcripts. After these meetings, the PhD candidate worked on grouping the codes together into different categories. Different colours were used to identify generated categories, e.g. traffic and slippery roads. These categories were later gathered and formed themes, e.g. safety and infrastructure (see appendix XXVI). Thus, each theme covered a set of categories. The working analytical Framework was produced during this stage. Due to the fact that iterations to the working analytical Framework can occur, a category named ‘other’ was created to prevent neglecting non-fitting data and/or deviant cases (Gale et al., 2013). After discussions during meetings, the research team interpreted that those quotations were encompassed by themes already identified, and there was no need to generate new themes. In the *fifth stage*, the application of the analytical Framework into the remaining transcripts took place. All codes and categories, previously established, were applied to all transcripts. Sets of codes were represented by categories in different colours to facilitate identification (see appendix XXVII). This action also took place to avoid writing names of codes each time in different sentences. No software was used to apply the analytical Framework.

In the *sixth stage*, a spreadsheet was formulated using Microsoft Excel (Redmond, Washington, USA) to chart data into the Framework matrix. The spreadsheet was created to facilitate inserting and reducing data in the Framework matrix (see appendix XXVIII). Charting data into the Framework matrix requires summarising data from each interview into the categories that were previously established. It is advised that efficient charting requires abilities from the researcher, so that data can be reduced while maintaining participants’ meaning and feelings regarding the topic being discussed. All relevant quotations that illustrated standpoints were included in the chart. Meetings between the researcher and supervisor were also held at this stage so that agreements could be reached regarding quotations and categories that were being allocated. In the *seventh stage*, the interpretation of data took place. An example of the completed framework matrix can be found in appendix XIV.

Procedures were followed to enhance trustworthiness of the findings of the present study. Nowell, Norris, White, & Moules (2017) recently discussed methods and illustrated processes for conducting thematic analysis while ensuring trustworthiness of results. In the present study, the PhD candidate was familiarised with the data by engaging with data. This was achieved by listening and reading files several times. Additionally, raw data, records and transcripts were maintained in organised archives. The present study involved peer debriefing (Given, 2008), while initial codes were being generated. The PhD researcher, his supervisor and research advisor held separate meetings in order to discuss analyses of data and interpretation. These meetings and discussions were documented. Diagrams were used to communicate ideas at meetings. Notes were registered and kept regarding the search for themes. The PhD researcher also searched for parental thoughts that did not support or differed to those of other parents.

6.3 Results

6.3.1 Descriptive

A total of eighteen parents, ten mothers and eight fathers, participated in the interviews. Children, eleven girls and seven boys, were aged eight to twelve years. Children's mean age was 10.2±1.6 years. Children's primary modes of transport to school were by car (55.6%), walking (33.3%) and by bus (5.6%). No child used their bicycle as a primary mode of transport to school. With regards to secondary modes of transport, i.e. a mode that was ever used but used less frequently than their primary mode, two children (11.1%) walked and only one child (5.6%) cycled to school. Table 6.3 shows ways that children commute to school according to parents, stratified by sex and mean age of children. Table 6.4 shows a description of ways that children commute to school with absolute and relative frequencies.

Table 6.2 Sex, mean age and ways that children commute to school.

Participant	Mother	Father	Daughter	Son	Mean age (SD)	Primary mode of transport	Secondary mode of transport
1	✓		✓		11	Bus	x
2	✓			✓	12	Car	Bicycle
3		✓	✓		11	Car	x
4	✓		✓		12	Walk	x
5	✓			✓	12	Walk	x
6	✓		✓		10	Walk	x
7		✓	✓		8	Walk	x
8		✓	✓		11	Train	x
9	✓			✓	8	Car	x
10		✓		✓	10	Car	x
11		✓	✓		8	Car	x
12	✓			✓	12	Walk	x
13	✓		✓		11	Walk	x
14		✓	✓		9	Car	x
15	✓		✓		9	Car	Walk
16		✓		✓	8	Car	x
17		✓	✓		9	Car	x
18	✓			✓	12	Car	Walk
Total	**10**	**8**	**11**	**7**	**10.2 (1.6)**		

Age of children in years. SD = standard deviation

Table 6.3 Description of ways that children commute to school with absolute and relative frequencies.

	Primary mode of transport	Secondary mode of transport
Car	10 (55.6%)	0 (0%)
Walk	6 (33.3%)	2 (11.1%)
Bus	1 (5.6%)	0 (0%)
Train	1 (5.6%)	0 (0%)
Bicycle	0 (0%)	1 (5.6%)

6.3.2 Themes

Analyses using the Framework approach yielded six key themes that cover several factors influencing decisions that parents make towards the way their children commute to school. The aspects were: *resources*, *safety*, *environment*, *social*, *infrastructure* and *perceived benefits of cycling*. The sections below provide a description of the main themes that arose from the analysis of the present study.

6.3.2.1 Resources

Many participants related their decisions for not cycling to school to the lack of resources. Indeed resources can influence decisions that parents make. For instance, not having a vehicle was reported as a reason for using public transportation to get to school. Parents reported that their children have to take the train or the bus to get to school as they did not own a vehicle. Besides not possessing a vehicle, some parents mentioned that their children lack resources to cycle to school. For instance, not all children had a bicycle. On the other hand, some children owned a bicycle, but the equipment that they had no longer suited them, i.e. the child had a bicycle that was too small for their age. A mother reported that such an issue was a reason for not allowing her child to actively commute to school.

> *So she didn't go riding, which she was very upset about but, I couldn't help it. I'm not just going to buy a bike just for that. Yeah, so, she has a bike, she loves riding, but her bike now is too small for her now. So she has no way, she needs to get a new bike. But, because, well, we cannot afford to buy one now anyhow so she has to deal with that. (Kristen, participant 1, mother of a girl aged 11 years).*

In England, programmes for teaching and helping children learn how to ride a bicycle have been developed. These programmes can also specifically contribute to the child becoming aware of dangers when commuting by bicycle in general. They help children overcome daily challenges on the streets, such as dealing with traffic at peak hours. These programmes were mentioned by parents during the interviews. Some parents judged these programmes to be very efficient as they believed that they can teach a child how to face and deal with adversities on the streets. Thus, cycling lessons, from a parental perspective, can potentially contribute to preventing accidents among children. Nonetheless, the course is not free of charge. Also, besides parents having to pay a fee for the course, additional equipment such as helmets are necessary. According to parents, high costs of *Bikeability* programmes prevent them from enrolling their children in these programmes, further not permitting actively commuting with their bicycles to school by themselves.

> *…it was fairly expensive that course, I mean, no kidding I think it was like £50 or something and really just for two hours or so. Then they were going a bit on the school yard I think and then they just went a bit outside on the road. I mean, £50 [giggle] so, but it was actually quite popular… and it was fully booked, within I*

don't know two weeks or so, so obviously parents here do like the idea that children get road safety with the bicycles. (Cara, participant 13, mother of a girl aged 11 years).

6.3.2.2 Safety

Although some parents demonstrated awareness of the importance of their children being physically active, the weather can increase their attention regarding their children's safety. For instance, on rainy days, not only can the traffic on the roads be different but, the roads become more slippery. This could increase chances of road accidents, according to some parents. Thus, the weather seemed to be one barrier related to active commuting in children as many parents reported that wet roads, for instance, could compromise their children's safety.

> *Yeah, I mean for me, again…if it's raining…it's just a little slippery, could cause a huge accident, you know, and he could be in hurt, I'd rather not put him through that, so if it is [bad] weather at all, I would not really, he is actually off the road. I wouldn't really want [him] to cycle while [it] is really tipping down or snowy or anything like that, I wouldn't want him to… just that slight little bump up the curve could slip the tire, yeah, and then I'm not there to help him, so I wouldn't want him to be in that situation. (Madeline, participant 2, mother of a boy aged 12 years).*

Similarly to slippery roads, the road traffic, in general, was a concerning issue for parents. For instance, some parents reported that they believe that their children are aware of dangers on the street, and they would probably know how to deal with road challenges, such as heavy traffic. However, the hypotheses of their children suffering a road accident or being hurt on the road during rush hours, was a factor preventing parents from allowing their children to engage in active commuting to school. Even though some children had participated in *Bikeability* programmes, some parents believed that traffic surrounding their neighbourhood or the school where their children study were a risk to be considered.

> *My daughter knows how to cycle and that took a couple of days at school for her to get a diploma related to cycling, this was good, but still I wouldn't trust, well I*

might trust her to be safe and not to do anything silly, I wouldn't let car drivers taking care of her. But it would be difficult to teach kids, it is mostly having a part of the road that is safe from cars. (Erik, participant 11, father of a girl aged eight years).

Another factor that could compromise a child's safety, according to parents, was the use of mobile phones. This is because some parents believe that mobile phones can drastically deviate a child's attention. However, no parent related their concern regarding carrying mobile phones to cycling. Some parents related these concerns related to general active commuting and not specifically active commuting by bicycle.

…when he is with his mobile he might not pay as much attention to the road and the second thing is that they had a couple of mobile phone snaps, you know when people come and take your mobile phone from you. I don't know I'm quite ambivalent with it, because, yeah, I think it is great that he has it, so he can call, but it also sets him up as a target for you know like mugging or this kind of stuff. It's difficult to say. (Julie, participant 12, mother of a girl aged 11 years).

On the other hand, some parents had different views on their children using mobile phones. For instance, some parents believed that it is a good idea for their children to have a mobile phone when they are outside. More specifically, children carrying mobile phones when actively commuting to school would contribute to their parents being able to reach them. Similarly, children would also be able to reach their parents in case of an emergency. Overall, parents reported that their children having a mobile phone could make them feel less concerned about their safety. A mobile phone would facilitate communication between children and parents while children are away or actively commuting to school.

…the mobile phone would be useful simply because it would allow us to get in contact with her at any time, so if we would consider finding out where about she is, we know that she has a mobile phone, so we can give her a call. Yeah, that would change my view slightly, but not significantly. (Ludwig, participant 14, father of a girl aged nine years).

Crime was an issue reported by parents during the interviews. In general, parents seemed to be very concerned about their children being targeted by criminals on the streets while walking or cycling to school. Some parents reported being even more concerned when it gets dark. Independently of possessing a mobile phone, some parents preferred to see their children at home before it gets dark. Other parents reported that neighbourhoods used to be safer in past decades, particularly when they grew up. Other parents said that they would be more willing to let their children cycle to school if there were more police in their neighbourhood streets.

> *I would be a bit less concerned if I see that there are more security officials walking on the street around the area that my daughter uses on her way to school. If I would see a lot of police officers around, if I see some security officials walking around, who might intervene in case something happens to my daughter, if I see that the UK has decided to let a lot of police officers walk around the town, that would make me feel that if anything is about to happen to my daughter, there would be police or security officers to intervene, that is one thing. (Ludwig, participant 14, father of a girl aged nine years).*

Some parents reported that they were concerned not only with their child's security when actively commuting to school, but with a safe community in general. For instance, a parent reported that to maintain security in a city a continuous process is necessary. Constant adaptations are needed so that people can feel safe. As a consequence of this maintenance of a city's security, parents would be more likely to change their minds with regards to letting their children actively commute to school. As it stands nowadays, some parents believe that an unsafe community is an important factor preventing their children from safely commuting to school alone.

> *I think the concern comes from general crime in the society. The impression that they [residents] have about crimes in the society, makes me think the way I am thinking, government rule in terms of increasing the level of security in the society would be helpful. But in terms of changing my mind, it must be a kind of a continuous process, something that would not happen overnight. It must be something that would happen over a long period of time to give me the impression that we are in a safe society, which I don't have much at the moment*

for youngsters being on their own. (Jason, participant 17, father of a girl aged nine years).

6.3.2.3 Environment

The main issues reported by parents in the *environment* theme were related to distance and season. Some parents reported that distance was a consideration when allowing their child to actively commute to school by bicycle. For instance, there was a parent that communicated that the fact that they lived too far from their child's school was an issue preventing them from letting their child engage in cycling to school. On the other hand, parents voiced that the fact that they lived too close to school was an inconvenience preventing their children from cycling to school, as further discussed below. However, distance alone may not be a barrier to cycling to school when adequate infrastructure was provided to ensure cycling to school was safe.

> *"It would be fine as long as we live at a reasonable distance and there is a safe way for him to cycle and there is some kind of cycle paths." (Bob, participant 16, father of a boy aged eight).*

Although living too far from school was discussed by parents as a barrier to active commuting, it was primarily discussed in the context of walking to school. In contrast, the fact that some children lived close to their schools seemed to be a factor preventing them from cycling to school. Some parents reported that they lived too close to the school to support their children to cycle to school. In these cases, walking seemed to be more convenient than preparing their bicycle to cycle. This is also because when children use their bicycles, they are required to lock their bicycles at school. Additionally, wearing the necessary gear to cycle, such as gloves and a helmet, demands extra time in the morning. Parents reported that it seemed that the time spent on setting up and wearing cycling gear could take longer than the trip to school itself.

> *Because it is literally five minutes away [giggle]. No, we live very close so, it would not be worth it, really, she has to cross just one road. Where we live now, I could drop her with the car in under a minute maybe [laugh]. It takes longer for me to take the car and drive than to get there. So, before that we were walking*

to the school and sometimes, I would pick her up with the car. (Cara, participant 13, mother of a girl aged 11 years).

From a parental perspective, seasons seem to play a role in the way children commute to school. This can be a major barrier for motivating children to actively commute to school throughout the year. For instance, in England, there is a radical change in the amount of sunlight during summer and winter months. Thus, in the winter not only cold temperatures can affect children commuting to school, but also minimum amounts of sunlight as it gets dark considerably earlier than in the summer. Overall, many parents believed that children should not be on the streets at night or when it is dark. Thus, chances of children actively commuting during winter are smaller.

I would not allow her to ride when it's dark, so like winter is coming, obviously I'm not…I wouldn't, allow her to take part in that one, you know. The thing is, because it's dark I want her to get home as soon as possible, so I wouldn't allow her to ride the bike. So, with the winter coming, no, that would be out of…, I would not allow it. She would have to dress properly and that sort of thing. (Kristen, participant 1, mother of a girl aged 11 years).

In contrast to winter, parents were more likely to let their children actively commute to school in summer. During the summer season days are longer, so children can also engage in after-school activities besides actively commuting to school. However, during the summer season most children are away from their schools due to summer holidays.

You know, if…during the summer months I'd say it's good weather, I want him to ride anyway. Just because it's good weather and to make use out of traffic. The traffic I get stuck in to take him there. You know I don't need to [be] stuck in traffic when he can actually cycle in 15 minutes to be there. So, yes, definitely, but if it's dripping down rain, I won't make him cycle, I do say to him perhaps one or two times per week I would like you to cycle. (Madeline, participant two, mother of a boy aged 12 years).

6.3.2.4 Social

Parents do not seem to have a definitive opinion with regards to whether or not having friends can be good for their children to actively commute to school. Some parents reported that their children being in a group of friends can either be a positive or a negative feature. Children may be more likely to get distracted in a group of friends, which could potentially make them less aware of road traffic and lead to an accident.

> *If she is going with friends, I would say, that would make a difference, yes. But I would still need to keep an eye on her because it all depends on the type of friends that she will be going to school with. So yes, if she goes with friends, that would make a slight difference in my mind but, with that being said, I would still need to keep an eye on her moves. (Ludwig, participant 14, father of a girl aged nine).*

While travelling with friends may facilitate active commuting, it is not uncommon for children to have friends in school who live in neighbourhoods that are far from their homes. Thus, the option of children actively commuting to school in a group of friends cannot be considered by all parents.

> *…he doesn't have any friends in the neighbourhood, his friends are all spread out from school, so we don't really mix with our neighbours. So there is… no, I don't know how would that really work. Really, and we have a big garden, we go to the park a lot so, there wouldn't be any need for him to spend time outside, you know, he can play in the garden, or he can go to other places. (Bob, participant 16, father of a boy aged eight years).*

6.3.2.5 Infrastructure

Issues with bicycle parking and cycle lanes were identified as areas of concern by parents. As previously mentioned, access to resources was a barrier that children faced to actively commute to school. Nevertheless, while children have to be prepared with appropriate bicycle sizes and equipment so that they can cycle to school, there are other issues that parents and children are not directly responsible for. For instance, schools may not have suitable places to park bicycles. On this perspective, a mother reported that commuting with a bicycle was not practical.

…we tried the bicycle first and, because he has to put his bicycle into the school, he can't park his bike outside the school into the gates. They said he is not allowed to do that. So, he has to go inside the school, put it in a special place, lock it up, put his helmet and etc. You know, even though it is much quicker to go with a bike, if you add, you know you have to get out of the house, get dressed, put the whole thing on, cycle and put it away. (Julie, participant 12, mother of a boy aged 12 years).

There are further issues preventing children from actively commuting that parents cannot directly change. These issues include a minimum amount of cycling lanes or total absence of cycling lanes on the roads. Many parents reported problems with pavements and cycling lanes. The lack of cycling lanes can compromise a child's safety on their way to school. Generally, parents reported being very concerned with the fact that their children would have to cycle on pavements or sidewalks to protect themselves from vehicles on the road. Additionally, parents reported that pavements are usually busy, or even congested during peak hours, with parents and children getting to or coming from school.

I guess cycle routes would be very useful, because some of the roads, especially at the school that she is going to now, are major roads going out of the city. So the general speed is high and there are not enough lanes to go from one lane to others. So cycling routes would be certainly important, both in terms of safety, general safety and driving safety. (Jason, participant 17, father of a girl aged nine years).

Concerns with cycling lanes were emphasised through comparisons between the United Kingdom with other European countries such as Denmark, the Netherlands and Germany. Some parents who had lived in these countries reported that in those countries using bicycles to commute are far more common than in England and this was largely due to better infrastructure such as adequate cycle lanes. One parent reported that, in other countries of Europe, it is not unusual for parents to attach a trailer to their bicycles so they can leave their kids in nursery schools and proceed with their journey to their workplaces with their bicycles. Overall, these parents shared similar views that, although there are cycling lanes in the United Kingdom most of the roads are not appropriate for cyclists.

> *I would not consider a bicycle because I personally think that the way roads are built here in the UK, in particular, are not meant to be used by bikes. I lived in Holland before and there were a lot of cycle paths and there are not many here in the UK. When I drive on the road myself, I can see how unsafe it is, there is no security for people that are using their bikes on the roads. So I would not let my daughter go to school on a bike, no. (Ludwig, participant 14, father of a girl aged nine years).*

6.3.2.6 Perceived Benefits of Cycling

Perceived benefits of cycling was one of the themes identified using the Framework approach. Although parents were able to report several barriers preventing their children from actively commuting to school, most parents were knowledgeable with regards to health-related consequences of active commuting in children. Some parents reported that, besides health-related benefits from cycling, they believe that cycling to school could potentially bring more joy to their child's daily lives. Other parents reported that their children would not only be able to get to school faster than walking, but they would also enjoy their ride to school with their bicycles. One parent reported that they believe that cycling to school can be more fun than walking.

> *Positive things are, your blood circulation is slightly more while cycling, I think it is more enjoyable, and obviously get there quicker and I think you're using more senses and it is a bit more fun riding to school, so overall, riding is probably more fun and more stimulating in all aspects than walking. (Trevor, participant seven, father of a girl aged eight years).*

Some parents reported different advantages related to their children cycling to school. For instance, besides direct health-related benefits of cycling on their child's health, some parents were aware that cycling could be an alternative option for children to engage in more PA. A parent reported that they understand that cycling can be more than a tool for active commuting as cycling early in the day could enhance chances of children having a better day. Another parent reported that cycling back home from school can have several advantages for children, such as helping them to relax after a full day dedicated to studies in school. Overall, parents reported that cycling can mostly be good for a child's well-being.

> *I can relate to the advantages of cycling, both in terms of being healthy and also especially at the end of the day. It would be a very good way of cooling off, I can see advantages. But this is really for going to school in case of, like, making yourself tired. But certainly in case of coming back from school, then yes, [for general health] it would be very useful. (Jason, participant 17, father of a girl aged nine years).*

6.4 Discussion

The present study aimed to explore parental perspectives and concerns regarding cycling to school in children. Although findings show that parents have positive perspectives towards active commuting in children, parents voiced different issues that can often prevent them from supporting their children in using bicycles to commute to school. Due to the fact that none of the children used cycling as a primary mode of commuting, some parents discussed walking as a form of commuting and also reported barriers to walking. The present section will discuss parental thoughts regarding their children actively commuting with bicycles in England.

Results of the systematic search in the literature review identified two qualitative studies about the feasibility of cycling as a form of active commuting among children. One study examining the suitability of cycling (Sisson et al., 2006) and another study describing barriers and facilitators regarding walking and cycling to school (Ahlport et al., 2008) were identified in the literature review. A quantitative study investigating whether or not a cycle training programme can improve children's cycling skills found that a cycle training programme was effective for increasing children's cycling skills (Ducheyne et al., 2013). Kerr et al. (2006), also using quantitative methods, documented that reduced quality of built environments and high parental concern can affect whether or not a child actively commutes.

Ahlport et al. (2008) interviewed parents and children and reported three categories of barriers and facilitators for walking and cycling to school: intrapersonal and interpersonal characteristics of children and parents, neighbourhood environment and school policies and environment, showing similar findings to the results of this study. For example, the study shows that barriers include fear of children being involved in a traffic accident, lack of sidewalks and bad weather. Sisson et al. (2006), after interviewing school principals, reported that schools had different policies for students using bicycles to actively commute, e.g. some schools had designated routes that students were permitted to use for cycling, and other schools did not permit students to commute by bicycle without obtaining parental permission. However, these studies took place in the United States, and the American context related to school policies for students may be different than in England. In the United States, there are specific policies for students to use school buses and bicycles to commute to school. Therefore, these findings might not be applicable to circumstances that parents in England face. In the United States, for instance, policies for students to use school buses can differ according to the school or the state the child resides in (Ahlport et al., 2008; Sisson et al., 2006). Thus, the present study adds parental perspectives on children cycling to school in England to the body of the literature. The following barriers were unfolded during data analyses using the Framework approach in the present study.

In the present study, parents reported that their children not having an appropriate bicycle size or not attending a *Bikeability* programme can prevent them from cycling to school. These factors influencing cycling were not reported by parents in other qualitative studies conducted in the United States (Ahlport et al., 2008; Sisson et al., 2006). Ducheyne et al. (2013), using quantitative data, reported that a cycle training programme increased children's cycling skills ($F = 46.9$; $P < 0.001$). The study demonstrated that a *Bikeability* course was effective to improve participant's cycling skills. These quantitative results are in line with thoughts reported by some parents in the present study.

Some parents in the present study reported no concern regarding letting their children actively commute with their bicycles as they became proficient in cycling after concluding a *Bikeability* course. Safety issues were common constraints reported by parents. Preoccupation with the weather, the traffic surrounding their neighbourhood or the school where their children study, for instance, were issues reported. Some parents reported that carrying a mobile phone can expose their children to hazards as they can more easily get distracted. Nevertheless, some parents believed that a mobile phone can be useful for children when considering active commuting on their own. Lastly, parents seem to be concerned regarding their children being targeted by criminals on the streets while walking or cycling to school. Parents said that if there were more security in the general society, they would be more willing to allow their children to actively commute to school. Our results are in line with findings from Ahlport et al. (2008) where personal safety barriers reported, by both parents and children, were fear of kidnapping, fear of their children walking alone outside, fear of children getting involved in an accident and bullies.

In the present study, some parents were not aware of whether or not their neighbourhood offered suitable infrastructure for cycling. Parents reported that commuting with a bicycle where they live was not practical. For instance, some parents reported that the school that their children attend did not have a suitable place to park bicycles. Concerns with the lack of cycling lanes on the way to school were reported and that, even though there are cycling lanes in the United Kingdom, most roads are not appropriate for cyclists. Similarly, Ahlport et al. (2008) heard from parents that the lack of infrastructure for cyclists was one of the major barriers for letting their children cycle to school.

In the present investigation, we found that the environment plays a role in parental decisions regarding their children actively commute to school. According to parents, walking or cycling to school was often not an option for children as they lived too far from school. Parents also reported that they lived too close to school. Thus, preparing to wear the helmet and gloves to use a bicycle to get to school would potentially take longer than the walk to school. There were parental thoughts regarding annual seasons. Parents reported that their children were not allowed to ride their bicycle when it is dark or rainy. Similar views were given by other parents saying that they would be more willing to let their children actively commute to school during summer months. In the research conducted by Ahlport et al. (2008) weather-related barriers, such as rain and cold temperatures, were reported by parents in the United States. Also, similarly to what parents reported in the present study, parents in the United States mentioned that short distance was a barrier preventing children from actively commuting as distances from school were under one and a half miles (Ahlport et al., 2008).

In addition to environment, parents reported that social aspects can influence their decisions on whether or not to support their children to walk or cycle to school. A parent reported that their child being with a group of friends would not contribute much to their security. In their opinion, children would pay even less attention to their surroundings and that could be risky. Another social aspect reported by parents was their children's lack of friends in the neighbourhood. In the study conducted by Ahlport et al. (2008), parents reported that having someone in the company of their children could be a facilitator for them to actively commute to school. This is due to the fact that fear of child abductions was an issue found in their study. Parents also reported that the person escorting their children to school can be an adult, a sibling or a friend. Although the research conducted by Sisson et al. (2006) found that social factors are likely to affect decisions surrounding children using bicycles to get to school in the state of Arizona, the authors did not specify these factors.

Parents acknowledged that active commuting can bring advantages and health-related benefits. Parents reported that cycling not only leads to health benefits and improved well-being, but that it can also take their children to places faster. It was reported that cycling to school early in the morning can be tiring but cycling back home from school can be a good way of getting rid of stress. Parents voiced that cycling can improve abilities of a child such as cognitive skills and coordination. Similar thoughts regarding the benefits of active commuting in children were reported by parents in the study conducted by Ahlport et al. (2008). The authors reported that parents of children who actively commuted saw active commuting as an alternative form of exercising. Thus, these parents were more willing to support their children to actively commute. The authors also reported that some parents moved closer to school in order to motivate their children to actively commute as it can favour independence in children. (Ahlport et al., 2008). Overall, the present research showed that parents were aware of the benefits of cycling to school.

Although the present study brings important evidence to this body of the literature, there are limitations that need to be taken into account. Analysis of the present study did not include a stratification of the number of parents whose children were active commuters and non-active commuters. To the best of our knowledge, this is the first study conducted in London investigating parental perspectives regarding active commuting in children using qualitative data. Nevertheless, the present study did not include demographic information of participants such as ethnicity, socioeconomic status and body weight status. Although analyses of the present study took into account methods for enhancing credibility and trustworthiness (Nowell et al., 2017), it is possible that the inclusion of this demographic information could have increased transferability of the present findings. There are issues related to using the telephone to perform interviews that should be taken into account as this method can limit rapport between the interviewer and participants. This can potentially influence responses from participants and their willingness to share details. Also, telephone interviews do not allow the interviewer to see further information, such as body language. Another issue related to this study is related to the closed nature of questions and potentially leading questions. These types of questions can potentially drive parents to provide responses with a biased perspective.

Lastly, reflexivity was not conducted in the present study. The achievement of reflexivity is not a simple task as the researcher must examine and judge their decisions that are taking place in each stage of the research project (Given, 2008). In the present study, it is believed that the fact that the PhD candidate was in the process of acquiring qualitative skills may have influenced the development of the topic guide and data collection. As the process was new for the PhD candidate, all relevant aspects to develop a topic guide in qualitative research could not be taken into account due to limited time. This may have had implications toward the topic guide of the present study being underdeveloped and potentially not delivering more extensive interviews. The PhD candidate is a father of a teenaged boy and this could have led him to see issues related to safety with a biased view, as participants were parents of younger children, i.e. 8 to 12 years old. For instance, an older child or a teenager is likely to be more independent and more streetwise than the younger children that were investigated in this study. The PhD candidate is a male, this could have influenced the development of the topic guide and data collection, as some sensitive issues or topics faced by girls on the streets, such as sexual harassment, might have been missed. It is believed that parents might be more comfortable talking about such topics with a female interviewer. The PhD candidate has a background related to engagement with sports, both as a practitioner and as a personal trainer. This history of sport might have influenced the development of the topic guide, the data collection and the data analysis, as the PhD candidate might have an affinity to perceive active commuting, e.g. both walking and cycling, as healthy and safe activities to be performed even by children.

The present study sought to maximise scientific rigour and credibility by thoroughly describing details of each stage of the project and further discussing limitations (Given, 2008). The methods section of the present chapter includes complete and transparent descriptions of the study approach, participant identification, development of the topic guide, data collection and data management and analysis. Transferability, or external validity, was also taken into account in the present research project (Nowell et al., 2017). Demographic data from parents, such as sex, were reported. Additionally, data from their children, such as sex and age, were reported. These demographic data were included in the scope of the present study to allow better understanding and contextualisation of results (Given, 2008). School policies for children to use bicycles can differ between cities and/or countries. Nevertheless, reporting clear procedures that were adopted to collect and analyse data, as well as information regarding participants' background, improves critical interpretation of findings. Also, it facilitates applicability in other contexts while maintaining trustworthiness.

In conclusion, a series of factors seem to prevent parents from supporting their children to actively commute to school in London. Parents fear their children being exposed to crime and bad weather conditions while actively commuting to school. The absence of cycling lanes and, long or short, distance from school are further issues preventing parents from supporting their children to cycle to school in London.

CHAPTER 7. GENERAL DISCUSSION AND CONCLUSIONS

The overall goal of this thesis was to investigate associations between PA, pain, injuries and, joint loading in children, and how these factors may affect recommendations regarding the type of PA that children should perform whilst taking environmental and personal barriers into consideration. A multimethod design was used to investigate the following aims. Firstly, chapter four aimed to investigate whether MPA and VPA were associated with pain and injuries in children and whether these associations differed between children with and without OW and OB. Secondly, chapter five aimed to investigate differences in joint loading, pain and perceived effort between walking and cycling, at similar physiological intensities in children. We also used two different methods to match physiological intensities from walking and cycling in order to be able to draw robust conclusions, assuming the results would be independent of the method used to match physiological load. Lastly, chapter six aimed to explore the barriers to children cycling as a means of active commuting, as active transport has been recommended in order to increase PA engagement in children (Wilkie et al., 2016). Findings are compared and contrasted to the current literature. Implications of the present findings are also described in the present chapter.

Overall, findings from chapter four showed that MPA and VPA were not predictors of pain or injuries in children. The association between PA and pain, and PA and injuries, respectively, also did not differ between children with and without OW/OB. As PA type was not measured in chapter four, it was not possible to determine if PA type was associated with pain. Therefore, chapter five compared joint loading, pain and effort between walking and cycling in children. Results from the study revealed that, at similar intensities, cycling generated less loading in the lower limbs of children than walking. No difference in pain was found between the two activities. Children reported less effort to walk on the treadmill than to perform HR matched cycling. Following PA recommendations in the literature, where it states that active transport should be encouraged in children (Wilkie et al., 2016), and results from chapter five regarding cycling, the study in chapter six explored parental perspectives on their children using a bicycle to actively commute. Findings revealed that a series of factors seem to prevent parents from supporting their children to actively commute to school in London. Although findings show that parents have positive perspectives towards active commuting in children, parents voiced different issues that can be barriers for their children to cycle to school. Barriers such as safety, limited resources and the environment, including traffic and weather, and lack infrastructure, prevent children from using a bicycle to actively commute.

Combined, these results suggest that whilst a non-weight bearing activity, specifically cycling, generates less joint loading than a weight bearing activity, there is no evidence that PA intensities, MPA and VPA, are associated with pain or injuries in children. Findings from the present thesis also indicate that children perceive no difference in pain while performing cycling and walking. This evidence suggests that joint loading during PA is not associated with pain in children. Although results suggest that PA intensities and PA type are not associated with pain, this evidence is limited to children with healthy weight as there was a small number of children with OW and OB in the study investigating joint loading and pain. Also, cycling and walking trials used to compare pain had relatively low intensities and short durations. Findings regarding physiological and biomechanical factors underlying participation in weight bearing and non-weight bearing PA, along with the barriers to participation in cycling as a form of active commuting identified by parents, indicate that cycling should not be recommended over walking for children at present.

Findings from chapter four are aligned with evidence in the literature, where it states that objectively measured PA does not seem to predict pain in children (Aartun et al., 2016; Sitthipornvorakul et al., 2011). However, our findings do not support findings from Silva et al. (2017) and Swain et al. (2016), where the authors found associations between subjectively measured PA and pain in children. It is possible that these studies reported associations between PA and pain due to possible inaccuracy related to subjective methods used to assess PA duration and intensity (Hidding et al., 2018). Results from the literature review indicate that only three studies have measured PA intensity in children. Two studies used a subjective measure (Silva et al., 2017; Swain et al., 2016) and one used an objective measure (Aartun et al., 2016). Silva et al. (2017) examined the association of self-reported PA and pain in nine different regions of the body in children. The authors found that more time spent in MPA was significantly associated with a higher probability of reporting pain. Swain et al. (2016) examined the association of pain with self-reported MVPA in children. The authors found that reduced participation in MVPA was associated with different types of pain, such as headache and stomach-ache, in boys and girls. Aartun et al. (2016) examined the association between objectively measured PA and spinal pain in children. The authors found no association between different levels of PA and spinal pain, cross-sectionally and longitudinally. There were limitations to these studies that chapter four aimed to overcome. These studies did not examine whether the association between PA and pain differ according to weight status of children. Also, these studies used questionnaires that allowed children to report pain in limited regions of the body. Chapter four also investigated whether the association between PA and pain differed according to weight status. The assessment of pain took into account whole body pain in children. Also, PA was objectively measured using accelerometry.

With regards to the relationship between PA and injuries, two studies that subjectively measured PA reported that VPA was associated with increased risk of injuries (Clark et al., 2008; Lowry et al., 2007). However, one study objectively measured PA and reported that MPA was not a predictor of upper extremity injuries in children (Nauta et al., 2017). Findings from chapter four are aligned with results from Nauta et al. (2017), as results from the study also indicate that PA does not predict injuries in children. These studies investigating the association between PA and injuries had limitations and chapter four also aimed to overcome them. Chapter four used a questionnaire that allowed children to report injuries to any region of the body and not only upper extremity injuries. Chapter four also investigated whether the association between PA and injuries differed according to weight status of children. These are important analyses as evidence shows that structural modifications in lower limbs of children, due to excess body weight, can lead to pain and diminish their engagement in PA (Nantel, Mathieu, & Prince, 2011). Nevertheless, as PA type was not assessed in chapter 4, it was not possible to investigate whether participation in a specific type of PA was related to pain that children reported. Thus, the study in chapter five, besides comparing joint loading from two different activities, aimed to investigate whether or not pain experienced by children differed from these activities.

Findings from chapter five showed that, during cycling, ankle moments, as well as shear and compressive forces in knee and ankle joints, were smaller compared to walking. These results were independent of how physiological load was matched between the two tasks. No statistical difference was detected in perceived pain between walking and both cycling conditions. Perceived effort was also assessed so that children were adequately informed regarding symptom differences between muscular fatigue and pain. Children reported less effort to walk on the treadmill than to perform HR matched cycling. The systematic search in the literature review indicated that no study aimed to compare joint loading, pain and perceived effort between walking and cycling in children. Lerner et al. (2016) examined how OB and duration of walking could affect loading in the knees of children. The authors found that PA duration was associated with increased joint loading. During treadmill walking, medial compartment loading was 1.78 times greater in participants with OB than in healthy-weight participants. Riddiford-Harland et al. (2016) aimed to examine how a weight bearing PA programme could affect the foot structure and change plantar pressure generated in children who were OW or obese. The authors found that a weight bearing PA programme did not alter the magnitude of peak plantar pressure distributions generated during the walking assessment.

Findings from the study in chapter five show that cycling seems to be a suitable PA for children as it generates lower joint loading than walking at the same intensity. However, as pain did not differ between walking and cycling, cycling cannot be recommended over walking to reduce pain based on the results of the study. It is believed that pain might be less during cycling than walking as cycling generates less joint loading. Evidence suggests that OW and OB are associated with discomfort and pain, specifically, in the foot and knee joints (Nantel et al., 2011). Evidence also shows that, among children, knee joints suffer altered joint loading during walking due to OB (Lerner et al., 2016). These issues can prevent children from engaging in recommended PA (Nantel et al., 2011). On the other hand, evidence suggests that active commuting should be encouraged in order to increase current low levels of PA in children (Wilkie et al., 2016). Active commuting in children may increase cycling participation as it can be moderate or vigorous intensity, depending on the exertion dedicated to the activity (U.S. Department of Health and Human Services, 2008), and therefore contributes to PA recommendations (Department of Health Physical Activity Health Improvement and Protection, 2011). Thus, in order to assess cycling as a form of active commuting among children, the study in chapter six aimed to explore the feasibility of cycling as a form of active commuting among children from a parental perspective.

The systematic search in the literature review also indicated that no study in England has investigated parental perspectives regarding active commuting to school in children. Findings from chapter six showed that there are important factors influencing the way children commute to school. Analyses using the Framework approach yielded six key themes that cover several factors influencing decisions that parents make towards the way their children commute to school. The themes identified were: resources, safety, environment, social, infrastructure and perceived benefits of cycling. The theme ‘resources’ was related to whether or not parents had, or were able to afford, the appropriate equipment or preparatory courses in order for children to be able to commute safely by bicycle. The theme ‘safety’ was related to obstacles on the road, within the general community or to individual training of children in order to safely use a bicycle. The theme ‘environment’ was related to distance from school and seasonal aspects. The theme ‘social’ was related to friendship and commuting by bicycle. The theme ‘infrastructure’ was related to bicycle parking and cycling lanes. Lastly, the theme ‘perceived benefits of cycling’ was related to the way parents perceived cycling for their children. Findings show that even though parents have positive perspectives towards active commuting in children, they voiced different issues that can often prevent them from supporting their children using bicycles to commute to school.

Overall, results showed that parents fear their children being exposed to crime and bad weather conditions while actively commuting to school. The absence of cycling lanes and long or short distances from school are further issues preventing parents from supporting their children to cycle to school in London. One study examining the suitability of cycling (Sisson et al., 2006) and another study describing barriers and facilitators regarding walking and cycling to school (Ahlport et al., 2008) were identified in the literature review. Both studies were conducted in the United States and documented different findings to each other. Sisson et al. (2006), after interviewing school principals, reported that schools had different policies for students using bicycles to actively commute. Ahlport et al. (2008) reported three categories of barriers and facilitators for both walking and cycling to school: intrapersonal and interpersonal characteristics of children and parents, neighbourhood environment and school policies and environment. Some barriers towards cycling reported by parents in chapter four are similar to barriers reported by Ahlport et al. (2008), where parents also reported that they fear their children being involved in a traffic accident and spending time alone outside. Ahlport et al. (2008) also reported that the lack of sidewalks and bad weather are barriers for children to walk or cycle to school. However, in the United States there are specific policies for students to use school buses and bicycles to commute to school. This suggests that their findings are not applicable to England as policies for students to use school buses, for instance, differ according to state laws (Ahlport et al., 2008; Sisson et al., 2006).

The present thesis has limitations that must be taken into account. With regards to chapter four, the study had a cross-sectional design and so the direction of association between PA and pain and injuries could not be determined. A cohort study would be more appropriate for determining the direction of the association by measuring PA before pain and injuries. However, as no associations were observed it is possible that no associations would be observed using a cohort study design. A larger sample and recruitment from a wider geographical area would allow better representation of the population. Even though efforts were made to create partnerships with weight management organisations, as previously described, only a few schools were able to cooperate. Also, there was a relatively low proportion of children with OW/OB included in the study. With regards to chapter five, analyses conducted in the study were not stratified according to children's body weight. This was not possible due to a very small number of children with OW and OB. Also, in chapter five, the external load was adjusted using a fast walking pace as a reference for cycling trials. Thus, it is unknown whether the magnitude of the results could have been different if children were asked to perform HR matched and/or VO_2 matched cycling trials and use these tasks as work load references for walking trials. Thus, in order to confirm joint loading magnitude differences between walking and cycling, further studies should investigate forces and moments using external loads from cycling as a reference for walking. Another limitation of this study was that the joint reaction forces derived from inverse dynamics do not consider individual muscle forces or antagonistic contraction surrounding ankle and knee joints. Lastly, with regards to chapter six, the qualitative analysis carried out did not include a stratification of the number of parents whose children were active commuters and non-active commuters. Also, it did not compare and contrast parental perspectives regarding cycling as a form of active commuting between children with and without OB. This would have, potentially, allowed comparisons and contrasts between parental thoughts, i.e. active commuters vs non-active commuters and also children with vs without OB. Demographic information of participants such as ethnicity, socioeconomic status and body weight status were not included in the study. Although analyses of the study took into account methods for enhancing credibility and trustworthiness (Nowell et al., 2017), it is possible that the inclusion of this demographic information would have increased transferability of findings.

The cost-benefit of narrowing guidelines for PA in children should be considered. One of the implications of the present thesis is that the present results do not provide sufficient evidence that cycling should be recommended over walking for children. These results should be seen as an initial insight that suggests an alternative PA type for certain paediatric populations, e.g. children with OW or OB. A certain amount of joint and bone loading is beneficial as it can contribute to optimising bone mass in children (Landry & Driscoll, 2012). However, evidence shows that in some situations excessive or increased physiological forces in the joints can lead to pain (Stovitz et al., 2008). In this case, non-weight bearing activities might be an alternative option for PA as it can evoke similar physiological benefits in children. Cycling, for instance, has been shown to elicit health-related benefits including the protection against excess body fat (Bere et al., 2011), to improve cardiorespiratory fitness (Maher et al., 2012) and to increase physical abilities such as agility, balance and reaction response (Lirgg et al., 2018). Thus, in situations where there is a predisposition for joint overloading, pain or injury, cycling seems to be a more suitable mode of exercise to achieve similar physiological benefits. Nevertheless, when investigating cycling for children with OW or OB, other joints that were not investigated in this study, e.g. within the lower back, should be considered.

Throughout the conduction of the present research project, lessons were learnt. These lessons will be shared and briefly discussed as they can contribute to future research examining similar variables in children. The process of identification and recruitment of vulnerable populations, such as children aged 8 to 12 years, can be difficult and complex. This is due to the fact that additional documentation, in addition to ethical clearance from the local ethical committee, is necessary to start the process of recruitment of children. More specifically, an enhanced certificate issued by the Disclosure and Barring Service (DBS) agency is necessary. This document certifies that the researcher is a suitable candidate for specific works or activities involving vulnerable populations. In addition to this, researchers in this area should consider different strategies to identify and recruit children. This is due to the fact that schools and other institutions where participants can be identified and recruited may not be willing to cooperate. Thus, for research projects aiming to investigate a large number of participants, alternative strategies to identify participants should be considered. For instance, researchers would benefit from being in contact with professionals responsible for dealing directly with paediatric clinics and children's hospitals. These places can, potentially, help researchers to get in contact with parents of children.

In summary, this thesis provides a basis for further research informing the advocacy of more differentiated PA recommendations, in particular in relation to weight bearing or non-weight bearing activity. Results from study 1 (chapter 4) indicated that time spent in MPA and VPA, respectively, was not associated with pain or injuries. These associations did not differ between children with healthy weight and those with OW and OB. However, it was hypothesised that type of PA, rather than duration or intensity, may be a better predictor of pain. Results from study 2 (chapter 5) suggest that a non-weight bearing activity reduces joint loading whilst providing a similar physiological benefit to weight bearing activity. Although, as with study 1, study 2 did not reveal any association between PA and pain, it is still possible that among certain children, such as those with excess body weight, intensive weight bearing activities result in joint forces that lead to pain or injury over time. This hypothesis was not tested in the current thesis. Future research should explicitly explore this. In the absence of this knowledge, our results still let us speculate that cycling, as a non-weight bearing activity, could be a more suitable PA for those populations who are more prone to excessive joint loading and joint pain. However, whilst cycling may be an appropriate PA for some children, other barriers relating to the child, their family or their environment may exist. Results from study 3 (chapter 6) revealed that, in the borough of Hillingdon in London, bad weather, lack of infrastructure, parents' safety concerns or affordability can be barriers to cycling as a means of active commuting. Thus, when considering the advocacy of cycling as a PA recommendation, environmental and personal factors preventing participation in cycling need to be considered in addition to the physiological benefits and potential biomechanical benefits of cycling over weight bearing activities.

CHAPTER 8. REFERENCES

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APPENDICES

Appendix I: Search strategy

PubMed

1. children
2. youth*
3. toddler*
4. teen*
5. infant
6. adolesc*
7. or/1-6 (note: combines all terms relating to children)
8. physical activit*
9. activit*
10. exercise
11. cycling
12. walking
13. acceleromet*
14. pedomet*
15. or/8-14 (note: combines all terms relating to activity)
16. pain
17. injur*
18. fracture*
19. or/17-18 (note: combines all terms relating to injuries)
20. joint load*
21. load*
22. weight bear*
23. joint reaction forces
24. non-weight bearing
25. kinetics
26. ground reaction forces
27. pedal reaction forces
28. inverse dynamics
29. forward dynamics
30. or/20-29 (note: combines all terms relating to joint loading)
31. commut*
32. active commut*
33. passive commut*
34. cycling
35. or/31-34 (note: combines all terms relating to active commuting)

Question 1 - 7 and 16 and 15

(Note combines terms relating to children, pain and activity to address question "what is association between **physical activity and pain** in children?")

Question 1 - 7 and 19 and 15

(Note combines terms relating to children, injuries and activity to address question "what is association between **physical activity and injuries** in children?")

Question 2 – 7 and 16 and 15 and 30

(Note combines terms relating to activity and joint loading to address question “what is the association between joint loading, physical activity and pain in children?")

Question 3 – 7 and 15 and 30

(Note combines terms relating to pain, joint loading and activity to address question "does joint loading differ between cycling and other types of activities in children?")

Question 4 - 7 and 35

(Note combines terms relating to children and active commuting to address question "what is the feasibility of cycling as a form of active commuting for children?")

SPORTDiscus

1. children
2. youth*
3. toddler*
4. teen*
5. infant
6. adolesc*
7. or/1-6 (note: combines all terms relating to children)
8. physical activit*
9. activit*
10. exercise
11. cycling
12. walking
13. acceleromet*
14. pedomet*
15. or/8-14 (note: combines all terms relating to activity)
16. pain
17. injur*
18. fracture*
19. or/17-18 (note: combines all terms relating to injuries)
20. joint load*
21. load*
22. weight bear*
23. joint reaction forces
24. non-weight bearing
25. kinetics
26. ground reaction forces
27. pedal reaction forces
28. inverse dynamics
29. forward dynamics
30. or/20-29 (note: combines all terms relating to joint loading)
31. commut*
32. active commut*
33. passive commut*
34. cycling
35. or/31-34 (note: combines all terms relating to active commuting)

Question 1 - 7 and 16 and 15

(Note combines terms relating to children, pain and activity to address question "what is association between **physical activity and pain** in children?")

Question 1 - 7 and 19 and 15

(Note combines terms relating to children, injuries and activity to address question "what is association between **physical activity and injuries** in children?")

Question 2 – 7 and 16 and 15 and 30

(Note combines terms relating to activity and joint loading to address question "what is the association between joint loading, physical activity and pain in children?")

Question 3 – 7 and 15 and 30

(Note combines terms relating to pain, joint loading and activity to address question "does joint loading differ between cycling and other types of activities in children?")

Question 4 - 7 and 35

(Note combines terms relating to children and active commuting to address question "what is the feasibility of cycling as a form of active commuting for children?")

Appendix II: Critical Appraisal Skills Programme checklists

Questions from the Critical Appraisal Skills Programme for case control studies

	Yes	Can't tell	No
Section A: Are the results of the trial valid?			
1. Did the study address a clearly focused issue?			
2. Did the authors use an appropriate method to answer their question?			
Is it worth continuing?			
3. Were the cases recruited in an acceptable way?			
4. Were the controls selected in an acceptable way?			
5. Was the exposure accurately measured to minimise bias?			
6. (a) Aside from the experimental intervention, were the groups treated equally?			
6. (b) Have the authors taken account of the potential confounding factors in the design and/or in their analysis?			
Section B: What are the results?			
7. How large was the treatment effect?			
8. How precise was the estimate of the treatment effect? effect?			
9. Do you believe the results?			
Section C: Will the results help locally?			
10. Can the results be applied to the local population?			
11. Do the results of this study fit with other available evidence?			

Questions from the Critical Appraisal Skills Programme for cohort studies

	Yes	Can't tell	No
Section A: Are the results of the study valid?			
1. Did the study address a clearly focused issue?			
2. Was the cohort recruited in an acceptable way?			
Is it worth continuing?			
3. Was the exposure accurately measured to minimise bias?			
4. Was the outcome accurately measured to minimise bias?			
5. (a) Have the authors identified all important confounding factors?			
5. (b) Have they taken account of the confounding factors in the design and/or analysis?			
6. (a) Was the follow up of subjects complete enough?			
6. (b) Was the follow up of subjects long enough?			
Section B: What are the results?			
7. What are the results of this study?			
8. How precise are the results?			
9. Do you believe the results?			
Section C: Will the results help locally?			
10. Can the results be applied to the local population?			
11. Do the results of this study fit with other available evidence?			
12. What are the implications of this study for practice?			

Questions from the Critical Appraisal Skills Programme for a qualitative research

	Yes	Can't tell	No
Section A: Are the results valid?			
1. Was there a clear statement of the aims of the research?			
2. Is a qualitative methodology appropriate?			
Is it worth continuing?			
3. Was the research design appropriate to address the aims of the research?			
4. Was the recruitment strategy appropriate to the aims of the research?			
5. Was the data collected in a way that addressed the research issue?			
6. Has the relationship between researcher and participants been adequately considered?			
Section B: What are the results?			
7. Have ethical issues been taken into consideration?			
8. Was the data analysis sufficiently rigorous?			
9. Is there a clear statement of findings?			
Section C: Will the results help locally?			
10. How valuable is the research?			

Questions from the Critical Appraisal Skills Programme for a systematic review

	Yes	Can't tell	No
Section A: Are the results of the review valid?			
1. Did the review address a clearly focused question?			
2. Did the authors look for the right type of papers?			
Is it worth continuing?			
3. Do you think all the important, relevant studies were included?			
4. Did the review's authors do enough to assess quality of the included studies?			
5. If the results of the review have been combined, was it reasonable to do so?			
Section B: What are the results?			
6. What are the overall results of the review?			
7. How precise are the results?			
Section C: Will the results help locally?			
8. Can the results be applied to the local population?			
9. Were all important outcomes considered?			
10. Are the benefits worth the harms and costs?			

Appendix III: Appraisal tool for Cross-Sectional Studies

Questions from the Appraisal tool for Cross-Sectional Studies

	Yes	No	Do not know
Introduction			
1. Were the aims/objectives of the study clear?			
Methods			
2. Was the study design appropriate for the stated aim(s)?			
3. Was the sample size justified?			
4. Was the target/reference population clearly defined? (Is it clear who the research was about?)			
5 Was the sample frame taken from an appropriate population base so that it closely represented the target/reference population under investigation?			
6. Was the selection process likely to select subjects/participants that were representative of the target/reference population under investigation?			
7. Were measures undertaken to address and categorise non-responders?			
8. Were the risk factor and outcome variables measured appropriate to the aims of the study?			
9. Were the risk factor and outcome variables measured correctly using instruments/ measurements that had been trialled, piloted or published previously?			
10. Is it clear what was used to determined statistical significance and/or precision estimates? (e.g., p values, CIs)			
11. Were the methods (including statistical methods) sufficiently described to enable them to be repeated?			
Results			
12. Were the basic data adequately described?			
13. Does the response rate raise concerns about non-response bias?			
14. If appropriate, was information about non-responders described?			
15. Were the results internally consistent?			
16. Were the results for the analyses described in the methods presented?			
Discussion			
17. Were the authors' discussions and conclusions justified by the results?			
18. Were the limitations of the study discussed?			
Other			
19. Were there any funding sources or conflicts of interest that may affect the authors' interpretation of the results?			
20. Was ethical approval or consent of participants attained?			

Appendix IV: Chapter 4. Ethical approval

Department of Life Sciences Research Ethics Committee
Brunel University London
Kingston Lane
Uxbridge
UB8 3PH
United Kingdom

www.brunel.ac.uk

12 April 2016

LETTER OF APPROVAL

Applicant: Mr Joao Greca

Project Title: Physical Activity Levels in Children

Reference: 2440-MHR-Mar/2016- 2773-2

Dear Mr Joao Greca

The Research Ethics Committee has considered the above application recently submitted by you.

The Chair, acting under delegated authority has agreed that there is no objection on ethical grounds to the proposed study. Approval is given on the understanding that the conditions of approval set out below are followed:

- 1. D4: Please add a point to state children of either sex can take part in the study;
- 2. There is no direct indication in the assent or information sheet for parents forms, that you will use skinfold measurements. To me this is an important measure about which both participant and parents/guardians should be informed prior to taking part. In the information sheet for parents you indicated that you will "assess child's weight" and I am not clear whether by "assessing the weight" you meant you would take skinfold measurement to see if the child is obese. If this is the case, please be specific about it, otherwise please indicate that measurements in the study include taking skinfold measurement. This can be shown by adding extra photos to the information sheet.
- The agreed protocol must be followed. Any changes to the protocol will require prior approval from the Committee by way of an application for an amendment.

Please note that:

- Research Participant Information Sheets and (where relevant) flyers, posters, and consent forms should include a clear statement that research ethics approval has been obtained from the relevant Research Ethics Committee.
- The Research Participant Information Sheets should include a clear statement that queries should be directed, in the first instance, to the Supervisor (where relevant), or the researcher. Complaints, on the other hand, should be directed, in the first instance, to the Chair of the relevant Research Ethics Committee.
- Approval to proceed with the study is granted subject to receipt by the Committee of satisfactory responses to any conditions that may appear above, in addition to any subsequent changes to the protocol.
- The Research Ethics Committee reserves the right to sample and review documentation, including raw data, relevant to the study.
- You may not undertake any research activity if you are not a registered student of Brunel University or if you cease to become registered, including abeyance or temporary withdrawal. As a deregistered student you would not be insured to undertake research activity. Research activity includes the recruitment of participants, undertaking consent procedures and collection of data. Breach of this requirement constitutes research misconduct and is a disciplinary offence.

Professor Christina Victor

Chair

Department of Life Sciences Research Ethics Committee
Brunel University London

Appendix V: Chapter 4. Information sheet for parents

College of Health and Life Sciences
Centre for Human Performance, Exercise and Rehabilitation

PARTICIPANT INFORMATION SHEET

Measuring Physical Activity Levels in Children

Background and purpose of this study

You and your child are being invited to participate in a study organised by researchers at Brunel University London. The purpose of the research is to investigate the association between physical activity and pain in children. Measuring physical activity levels in children and possible pain or discomfort that children might be experiencing will help to identify whether the intensity or amount of physical activity is related to pain or discomfort. Such knowledge could help children to practice physical activity without experiencing pain, which in turn could lead to more physical activity and a healthier lifestyle.

Activity monitor

What will you and your child have to do?

We will ask you to answer a short questionnaire about demographic information, i.e. child's age, date of birth, country of birth. We will assess your child's skinfold thickness, weight, standing and sitting height. We will ask your child to complete a questionnaire about his/her pain in the past 7 days and to wear a small activity monitor. The monitor needs to be worn around his/her waist, at the right hip for seven consecutive days, except for when swimming, showering or during other water activities.

What are the benefits of taking part in this study?

You and your child will learn about the importance of physical activity, and we will tell you how active he/she is.

Skinfold thickness

What are the risks?

There is a minor risk due to fall on the accelerometer. However, it is unlikely that falling on the accelerometer will harm your child or induce pain. Your child does not need to change his/her daily routine in order to wear the accelerometer on his/her hip.

What if something goes wrong?

In the highly unlikely event that your child is harmed in any way by taking part in this study, there are no special compensation arrangements, unless your child is harmed by someone's negligence. In this case you may have grounds for legal action but you may have to pay for it.

If you have any concerns or complaints about the conduct of the researchers or the study please contact Professor Christina Victor (Chair of the Research Ethics Committee, College of Health and Life Sciences) Christina.Victor@brunel.ac.uk

What will happen to the results of the research study?

The results of this study will be presented in a doctoral thesis and published in an academic journal. We will also share the study results with parents and researchers at conferences.

Who is organising and funding the research?

The research is being organised by researchers from Brunel University London. The research team includes Mr João Greca who is a PhD researcher sponsored by the Brazilian federal government, Dr Thomas Korff and Dr Jennifer Ryan, who are lecturers in the College of Health and Life Sciences at Brunel University London.

What are the indemnity arrangements?

This study is covered by standard institutional indemnity insurance. Nothing in this document restricts your rights.

Who has reviewed the study?

This study has been reviewed and approved by the Research Ethics Committee of the College of Health and Life Sciences, Brunel University London.

Confidentiality

An identification code will be used for all participants. Neither your or your child's name nor any personal information will be stored with any data that will be collected. Only the investigators will be able to reconcile your results with your child's identity. Any information that is obtained in connection with this study will remain confidential and will only be disclosed with your full permission.

Freedom to withdraw

Your participation is completely voluntary. Your decision whether or not to allow your child to participate will not affect your relationship with Brunel University London. If you decide to participate, you are free to withdraw your approval for participation at any time without having to give any reasons and without penalty.

If you and your child are interested in participating, or if you have any questions about this study, please **contact us** using the information below:

Mr João Greca
PhD Researcher
Tel: 07935 004054 || E-mail: Joao.DeAguiarGreca@brunel.ac.uk

Dr Jennifer Ryan
Lecturer in Physiotherapy
Tel: 01895 268702 || E-mail: Jennifer.Ryan@brunel.ac.uk

CONSENT FORM

STATEMENT

1. I agree to my child participating in this project;
2. I have read the Research Participant Information Sheet;
3. I had an opportunity to ask questions and discuss this study;
4. I understand that I will not be referred to by name in any report concerning the study;
5. I understand that my child's participation is voluntary and that he/she may withdraw from the research at any time, without giving any reason. My or his/her decision not to participate will not alter the treatment I would normally receive now or in the future;
6. I have received satisfactory answers to all my questions;
7. I agree to these results being used for educational and research purposes on the condition that my privacy is respected.

Parent or guardian's name: ____

Parent or guardian's signature: ____

Child's name: ____ Year: ___________

Date: ____

	Yes	No
Are you happy with us taking pictures that might be used for scientific communications such as posters or power point presentations?	☐	☐
Are you interested in further studies, and if so are you happy for us to contact you?	☐	☐

E-mail address and/or telephone: ____

Appendix VI: Chapter 4. Assent form for children

College of Health and Life Sciences
Centre for Human Performance, Exercise and Rehabilitation

Information sheet and assent form
Measuring Physical Activity in Children

What is a research study?

Research studies help us learn new things. If we have a question, we try to find the answer.

This information sheet describes our research and the choice that you have to take part in it. We want you to ask us any questions that you have. You can ask questions any time.

Important things to know…

You get to decide if you want to take part in this research study or not. You can say 'Yes' or you can say 'No'. In case you don't want to take part in this research study nobody will be upset. Also, if you say 'Yes', you can always say 'No' later.

Why are we doing this research?

We are looking to find out how much physical activity children are doing and whether it is related to any pain or discomfort such as knee or ankle pain.

What would happen if I joined this research?

If you decide to take part in the research, we would ask you to do the following:

- Wear a small device on your hip; it will be attached to your clothes for 7 days in a row.
- Take it off when you go to sleep and when you go swimming or have a bath/shower.
- We will measure your weight, skinfold thickness, hip, waist and how tall you are.
- Mark a scale if you feel any pain on your knees or ankle

Activity monitor

Scale

Not hurting
No discomfort ______________________________
No pain

Hurting a whole lot
Very uncomfortable
Severe pain

Are there any downsides if I take part in this research?

You don't have to change what you usually do but it's important that you wear the activity monitor for 7 days. If you forget to wear it on one day you can wear it for an extra day. You can take it off when you go to sleep and when you go swimming or have a bath/shower.

Could the research help me?

In order to grow up healthy it is very important to be physically active every day. By taking part in this study the researchers will know how much physical activity you are doing and this would allow the research team to advice whether the level of activity is appropriate for you.

What else should I know about the research?

If you want to stop, please tell the researchers. You can also ask questions at any time. Take the time you need to make your choice.

Is there anything else?

If you want to be in the research after we talk, please write your name below. I will write my name too. This shows we talked about the research and you want to take part.

Have all your questions have been answered? ☐

Do you understand that you can stop taking part at any time? ☐

If you are happy to take part please tick this box. ☐

Name of Participant ______________________________ Year______________
(To be written by child)

Participant number _____________ *Serial number* ______________________ *Date* _____________
(To be written by researcher)

Appendix VII: Body composition assessment

Skinfold equations for estimating body fatness in children, aged 8 to 18, using the percent fat from density, water and bone (PFDW) approach proposed by Slaughter et al. (1988):

Males: PFDWB = .735 (triceps + calf) + 1.0

Females: PFDWB = .610 (triceps + calf) + 5.1

Slaughter, M. H., Lohman, T. G., Boileau, R. A., Horswill, C. A., Stillman, R. J., van Loan, M. D., & Bemben, D. A. (1988). Skinfold Equations for Estimation of Body Fatness in Children and Youth. *Human Biology*, 60(5), 709–723.

Appendix VIII: Socioeconomic status assessment

The Family Affluence Scale

1. Does your family own a car, van or truck?

- ☐ No
- ☐ Yes, one
- ☐ Yes, two or more

2. Do you have your own bedroom for yourself?

- ☐ No
- ☐ Yes

3. During the past 12 months, how many times did you travel away on holiday with your family?

- ☐ Not at all
- ☐ Once
- ☐ Twice
- ☐ More than twice

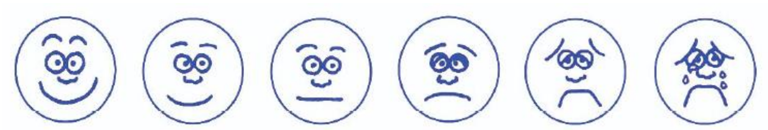
4. How many computers does your family own?

- ☐ None
- ☐ One
- ☐ Two
- ☐ More than two

Appendix IX: Pain and injury assessment

Visual analog scale

Rate **any pain you had in the last seven days**. If you had no pain this week, put a mark at the end of the line by the happy face. If the pain you had was some hurting, put a mark by the middle of the line. If the worst pain you had was a whole lot of pain, put a mark by the sad face.



Not hurting		Hurting a whole lot
No discomfort	____	Very uncomfortable
No pain		Severe pain

During the past 12 months, how many times were you injured and had to be treated by a doctor or nurse?

Answer: ____

Appendix X: STATA® protocol for conducting pain and injuries analyses

Analysis with MPA

```
tabstat painweek, s(min max mean sd iqr p50)
hist painweek
qnorm painweek

tabstat mpa, s(min max mean sd iqr p50)
hist mpa
qnorm mpa

tabstat age bmi waist hip bodyfat ses injury, s(min max sd mean p50 iqr)
hist age
hist waist
hist hip
hist ses
hist bodyfat

tab ow
tab sex
tab sescat

regress painweek age
regress painweek ses
regress painweek sex
regress painweek i.sescat
regress painweek waist
regress painweek bmi
regress painweek ow
regress painweek hip
regress painweek injury
regress painweek bodyfat

regress mpa age
regress mpa ses
regress mpa sex
regress mpa i.sescat
regress mpa waist
regress mpa bmi
regress mpa ow
regress mpa hip
regress mpa injury
regress mpa bodyfat

regress painweek mpa

regress painweek mpa age

regress painweek mpa sex

regress painweek mpa ses

regress painweek mpa i.sescat

test 1.sescat=2.sescat=3.sescat

regress painweek mpa waist

regress painweek mpa hip
```

```
regress painweek mpa bodyfat

regress painweek mpa bmi

regress painweek mpa ow

regress painweek mpa injury

regress painweek mpa if ow==0

regress painweek mpa if ow==1

regress painweek c.mpa##i.ow

regress painweek mpa

regress painweek mpa age sex i.sescat injury

regress painweek mpa age sex i.sescat injury bmi

regress painweek mpa age sex i.sescat injury bmi bodyfat

regress painweek mpa age sex i.sescat injury bodyfat

regress painweek mpa age sex i.sescat injury bmi

regress painweek mpa age sex i.sescat injury bmi
predict r, res
predict fv

scatter r painweek
hist r
qnorm r

gen logpain=log(painweek)
hist logpain

regress logpain age sex i.sescat injury bmi
predict res2, res
predict fv3

scatter res2 logpain
scatter res2 fv3
qnorm res2

gen pain=1 if painweek!=0
replace pain=0 if pain==.

logistic pain mpa
logistic pain mpa age sex i.sescat injury bmi

regress painweek c.mpa##i.ow

regress painweek c.mpa#i.ow

regress painweek mpa ow c.mpa#i.ow

regress painweek c.mpa##i.ow
```

```
regress painweek c.mpa##i.ow age sex i.sescat injury

regress painweek mpa ow c.mpa#i.ow age sex i.sescat injury
lincom mpa+c.mpa#0.ow

lincom mpa+c.mpa#1.ow

regress painweek c.mpa##i.ow age sex i.sescat injury

predict res4,res
predict fv4
scatter res4 painweek
qnorm res4

regress logpain c.mpa##i.ow age sex i.sescat injury

predict res5,res
predict fv5
scatter res5 painweek
qnorm res5
scatter res5 fv5

gen mpa2=mpa^2

regress logpain c.mpa##i.ow mpa2 age sex i.sescat injury

*Repeat analysis with VPA*


*Analysis of injury data*

rename _all, lower
rename secmoderate_upper mpa
rename secvigorous_upper vpa
rename secbouts_upper mvpa
rename pain7days painweek

list participant if mpa==0
list participant if vpa==0

drop if mpa==0

codebook bmicate
gen ow=1 if bmicat==2 | bmicat==3
replace ow=0 if bmicat==1
tab ow bmicat

hist injury
tabstat injury, s(mean min max sd p50 iqr)

tabstat injury, s(mean min max sd p50 iqr) by(ow)

poisson injury age
poisson injury sex
poisson injury i.sescat
test 1.sescat=2.sescat=3.sescat
poisson injury waist
poisson injury hip
poisson injury bmi
poisson injury ow
```

```
poisson injury bodyfat

reg mpa age
reg mpa sex
reg mpa i.sescat
test 1.sescat=2.sescat=3.sescat
reg mpa waist
reg mpa hip
reg mpa bmi
reg mpa ow
reg mpa bodyfat

nbreg injury mpa, irr

nbreg injury mpa age, irr
nbreg injury mpa sex, irr
nbreg injury mpa i.sescat, irr
nbreg injury mpa bmi, irr
nbreg injury mpa ow, irr
nbreg injury mpa bodyfat, irr
nbreg injury mpa hip, irr

nbreg injury mpa age sex i.sescat i.ow, irr

nbreg injury mpa age sex i.sescat i.ow bodyfat, irr
nbreg injury mpa age sex i.sescat i.ow waist, irr
nbreg injury mpa age sex i.sescat i.ow hip, irr

nbreg injury c.mpa##i.ow age sex i.sescat, irr

*Repeat the code for VPA analysis*
```

Appendix XI: Chapter 5. Information sheet for parents

PARTICIPANT INFORMATION SHEET

Biomechanical evaluation of walking and cycling in children

Background and purpose of this study

You and your child are being invited to participate in a study organised by researchers at Brunel University London. The purpose of the research is to compare biomechanical risk factors between walking and cycling in children. Assessing different types of physical activity in children will help identify the most appropriate and enjoyable physical activity type for children. Such knowledge could increase physical activity levels, which in turn would lead to a healthier lifestyle.

What will you and your child have to do?

You and your child will visit the Biomechanics Laboratory at Brunel University London in Uxbridge on one occasion lasting approximately 90 minutes. During the visit, we will first assess your child's weight and height. It is advised that your child wears light clothes as all measurements will be made fully clothed (without shoes). After this, we will ask your child to perform two exercises: walking on a treadmill and cycling on a stationary bicycle.

Cycling

During the cycling activity we will measure your child's motion by means of a 3D motion analysis system. For this purpose, we will place reflective markers on your child's feet, knees and hips. After this, your child will be asked to pedal on the stationary bicycle for approximately 15 minutes at up to three different intensities. Using specialised pedals, we will also measure the forces that your child will apply to the pedal of the cycle ergometer.

Walking

Similarly to the cycling session, we will use reflective markers on your child's feet, knees and hips to measure your child's motion while walking on the treadmill. After this, your child will walk on a treadmill for about 10 minutes. Using an instrumented treadmill, we will also measure the forces that your child will apply to the treadmill.

What are the benefits of taking part in this study?

Your child will learn about the advantages and disadvantages of different physical activities. In addition, your child will learn about the principles of scientific research, as we will explain all procedures in a child-appropriate manner.

What are the risks?

The risks associated with this study are minor. Considering that your child will perform physical activities using a treadmill, there is a possibility of falling off of the equipment. However, your child will not be requested to run or practice strenuous intensity of physical activity, therefore the possibility of injury is extremely low. The markers are attached with double sided tape. Therefore, if you are aware any allergies to sticky tape or glue, please let us know.

What if something goes wrong?

In the highly unlikely event that your child is harmed in any way by taking part in this study, there are no special compensation arrangements, unless your child is harmed by someone's negligence. In this case you may have grounds for legal action but you may have to pay for it. Regardless of this, if you wish to complain, or have any concerns about any aspect of the way your child has been approached or treated during the course of this study, you can ask to speak with one of the researchers who will do their best to answer your questions (please see contact details below). If you remain unhappy and wish to complain formally, you can do this through a University Complaints Procedure. Details can be obtained from the University.

What will happen to the results of the research study?

The results of this study will be presented in a doctoral thesis and published in an academic journal. We will also share the study results with parents and researchers at conferences.

Who is organising and funding the research?

The research is taking place at Brunel University London. The research team includes Mr Joao Greca who is sponsored by the Brazilian government, Dr Thomas Korff and Prof Bill Baltzopoulos (College of Health and Life Sciences at Brunel University London).

What are the indemnity arrangements?

This study is covered by standard institutional indemnity insurance. Nothing in this document restricts your rights.

Who has reviewed the study?

This study has been reviewed and approved by the Research Ethics Committee of the College of Health and Life Sciences, Brunel University London.

Confidentiality

An identification code will be used for all participants. Neither your or your child's name nor any personal information will be stored with any data that will be collected. Only the investigators will be able to reconcile your results with your child's identity. Any information that is obtained in connection with this study will remain confidential and will only be disclosed with your full permission.

Freedom to withdraw

Your participation is completely voluntary. Your decision whether or not to allow your child to participate will not affect your relationship with Brunel University London. If you decide to participate, you are free to withdraw your approval for participation at any time without having to give any reasons and without penalty.

If you and your child are interested in participating, or if you have any questions about this study, please contact us using the information below:

Mr João Greca
PhD Researcher
Tel: 07935004054 || E-mail: Joao.DeAguiarGreca@brunel.ac.uk

Dr Thomas Korff
Senior Lecturer in Biomechanics
Tel: 01895266477 || E-mail: Thomas.Korff@brunel.ac.uk

CONSENT FORM

Biomechanical evaluation of walking and cycling in children

STATEMENT

1. I agree to my child participating in this project;
2. I have read the Research Participant Information Sheet;
3. I had an opportunity to ask questions and discuss this study;
4. I understand that I will not be referred to by name in any report concerning the study;
5. I understand that my child's participation is voluntary and that he/she may withdraw from the research at any time, without giving any reason. My or his/her decision not to participate will not alter the treatment I would normally receive now or in the future;
6. I have received satisfactory answers to all my questions;
7. I agree to these results being used for educational and research purposes on the condition that my privacy is respected.

Parent or guardian's name: ____

Parent or guardian's signature: ____

Date: ____

	Yes	No
Would you like to receive a summary of the results by e-mail?	☐	☐
Are you happy with us taking pictures that might be used for scientific communications such as posters or power point presentations?	☐	☐
Are you interested in further studies, and if so are you happy for us to contact you?	☐	☐

E-mail Address: ____

Appendix XII: Chapter 5. Assent form for children

Information and Assent Form

Walking and cycling in children

☺ **What is a research study?**

Research studies help us learn new things. If we have a question, we try to find the answer. This information sheet describes our research and the choice that you have to take part in it. We want you to ask us any questions that you have. You can ask questions any time.

Important things to know…

You get to decide if you want to take part in this research study or not. You can say 'Yes' or you can say 'No'. In case you don't want to take part in this research study nobody will be upset. Also, if you say 'Yes', you can always say 'No' later.

☺ **Why are we doing this research?**

We are looking to find what would be the most enjoyable physical activity type for children.

☺ **What would happen if I joined this research?**

If you decide to take part in the research, we would ask you to do the following:

- Come to Brunel University London for 90 minutes including breaks
- Let us take your height and weight. You will just need to take off your shoes
- Sit on our bike suited for how tall you are
- Let us put some reflective stickers on your feet, knees and legs then record you cycling and walking for about 15 minutes each. You can take breaks
- You will mark a scale

Scale

Not hurting / No discomfort / No pain ______________________________ Hurting a whole lot / Very uncomfortable / Severe pain

Reflective stickers

Are there any downsides if I take part in this research?

Sitting on the bike for a long time could be a bit uncomfortable. Also walking on a treadmill is a bit different than walking on the streets, but you can stop if you want at any time.

Will it help me?

Finding the most enjoyable physical activity for children may help you to choose which activity you enjoy more.

What else should I know about the research?

If you want to stop, please tell the researchers. You can also ask questions at any time. Take the time you need to make your choice.

Is there anything else?

If you want to be in the research after we talk, please write your name below. I will write my name too. This shows we talked about the research and you want to take part.

Do all your questions have been answered? ☐

Do you understand that you can stop taking part at any time? ☐

If you are happy to take part please tick this box. ☐

Name of Participant ______________________________

(To be written by child)

Printed Name of Researcher ______________________________

Signature of Researcher ______________________________

Date ______________________________

Appendix XIII: Chapter 5. Ethical approval

Brunel University London

Department of Life Sciences Research Ethics Committeee
Brunel University London
Kingston Lane
Uxbridge
UB8 3PH
United Kingdom

www.brunel.ac.uk

7 January 2016

LETTER OF APPROVAL

Applicant: Mr Joao Greca

Project Title: Biomechanical evaluation of walking and cycling physical activities in obese children

Reference: 0523-MHR-Jan/2016-1202

Dear Mr Joao Greca

The Research Ethics Committee has considered the above application recently submitted by you.

The Chair, acting under delegated authority has agreed that there is no objection on ethical grounds to the proposed study. Approval is given on the understanding that the conditions of approval set out below are followed:

- The agreed protocol must be followed. Any changes to the protocol will require prior approval from the Committee by way of an application for an amendment.

Please note that:

- Research Participant Information Sheets and (where relevant) flyers, posters, and consent forms should include a clear statement that research ethics approval has been obtained from the relevant Research Ethics Committee.
- The Research Participant Information Sheets should include a clear statement that queries should be directed, in the first instance, to the Supervisor (where relevant), or the researcher. Complaints, on the other hand, should be directed, in the first instance, to the Chair of the relevant Research Ethics Committee
- Approval to proceed with the study is granted subject to receipt by the Committee of satisfactory responses to any conditions that may appear above, in addition to any subsequent changes to the protocol.
- The Research Ethics Committee reserves the right to sample and review documentation, including raw data, relevant to the study.
- You may not undertake any research activity if you are not a registered student of Brunel University or if you cease to become registered, including abeyance or temporary withdrawal. As a deregistered student you would not be insured to undertake research activity. Research activity includes the recruitment of participants, undertaking consent procedures and collection of data. Breach of this requirement constitutes research misconduct and is a disciplinary offence.

Professor Christina Victor

Chair

Department of Life Sciences Research Ethics Committeee
Brunel University London

Appendix XIV: Chapter 5. Recruitment strategy

The recruitment process of the present study occurred using the following strategies. First, the PhD candidate went to the administrative headquarters of the London Borough of Hillingdon in order to meet with assistants and professionals of the health and family sector of the borough. A first meeting was arranged, and the research project was then introduced and explained to attendants of the meeting by the PhD candidate and his supervisor. After understanding the importance of the project, access to the Fit Teen Club was granted. The Fit Teen Club is a physical activity programme for children that takes place at the Hillingdon Sports & Leisure Complex in Uxbridge, London. Due to minimum response from parents, as only few children were attending the Fit Teen Club scheme, no participant was recruited from this physical activity programme.

Supervisors of child weight management programmes in other areas of London were then contacted primarily by e-mails and phone calls. After arranging new face-to-face meetings to introduce the present research project to these supervisors, access to MyTime Active and North West London NHS Foundation Trust were granted in order to talk to parents of children. The PhD researcher offered to volunteer and provide help to Physical Activity Leaders at MyTime Active sessions. A volunteering support was provided during a three-month period at different physical activities sessions by the PhD candidate. Only one parent from MyTime Active agreed to let their children take part in the study. At the same period, the PhD candidate presented the research project to other clubs that were offering physical activity programmes for children in London. The Hillingdon Triathletes club was contacted, and they agreed to share flyers inviting members and friends of club. The Slipstreamers cycling club, where the PhD candidate also volunteered for three months prior to data collection, was also contacted. The Slipstreamers cycling club allowed the PhD candidate to talk to parents about the research project.

While offering voluntarily help or assist in the physical activity clubs described above, the PhD candidate gathered information about all primary and secondary schools in the London Borough of Hillingdon. A total of 50 primary schools and 21 secondary schools were identified. These schools were contacted to recruit, also, participants for the other studies in the present thesis. Some schools requested additional material regarding the research project, e.g. official letters were sent via traditional postal service, to consider participation in the study. All schools declined access for recruiting students. After trying to recruit participants from schools, help was sought from the Widening Access Department at Brunel University London. The department connected the research team with three schools in the London Borough of Hillingdon. Also, internal e-mails were sent to staff of Brunel University London that had children. The recruitment process described lasted for 18 months.

Appendix XV: Biological maturity assessment

Equations proposed by Mirwald et al. (2002) to estimate biological maturity in children.

Boys

Maturity Offset = -9.236 + 0.0002708 x Leg Length and Sitting Height interaction - 0.001663 x Age and Leg Length interaction + 0.007216 x Age and Sitting Height interaction + 0.02292 x Weight by Height ratio.

Girls

Maturity Offset = -9.376 + 0.0001882 x Leg Length and Sitting Height interaction + 0.0022 x Age and Leg Length interaction + 0.005841 x Age and Sitting Height interaction – 0.002658 x Age and Weight interaction + 0.07693 x Weight by Height ratio.

Mirwald, R. L., Baxter-Jones, A. D. G., Bailey, D., & Beunen, G. P. (2002). An assessment of maturity from anthropometric measurements. *Medicine and Science in Sports and Exercise*, 34(4), 689–94. https://doi.org/10.1097/00005768-200204000-00020

Appendix XVI: Perceived effort assessment

Children's Effort Rating Table

- ☐ 1 . . . . . . Very, Very Easy
- ☐ 2 . . . . . . Very Easy
- ☐ 3 . . . . . . Easy
- ☐ 4 . . . . . . Just Feeling a Strain
- ☐ 5 . . . . . . Starting to Get Hard
- ☐ 6 . . . . . . Getting Quite Hard
- ☐ 7 . . . . . . Hard
- ☐ 8 . . . . . . Very Hard
- ☐ 9 . . . . . . Very, Very Hard
- ☐ 10 . . . . . . So Hard I am Going to Stop

Appendix XVII: Pain assessment

Visual analog scale

Rate **how you feel now**. If you have no pain put a mark at the end of the line by the happy face. If you have some pain, put a mark near the middle of the line. If you have a lot of pain, put a mark by the sad face.

Not hurting		Hurting a whole lot
No discomfort	____	Very uncomfortable
No pain		Severe pain

Appendix XVIII: MATLAB protocol for measuring joint forces

```
% joint_powers_Joao_v1

clear all; close all; fclose all;

% -------------------------------------------------------------------
% read file and filter data ----------------------------------------
% -------------------------------------------------------------------
% filename_a=input('Type in the analogue filename ','s');
% filename_v=input('Type in the video filename ','s');
%cranklength=.171;
ID=input('Type in file ID ', 's');
% filename_a=[ID '.anc'];
% filename_v=[ID '.trc'];

filename_v=uigetfile('*.trc', 'Pick the trc file');
filename_a=uigetfile('*.anc', 'Pick the anc file');

% filename_a='Trimmed_Cycling2_10cycles1.anc' %[ID '.anc'];
% filename_v='Trimmed_Cycling2_10cycles1.trc' % [ID '.trc'];
% filename_a='Trimmed_ACSM2_10cycles1.anc' %[ID '.anc'];
% filename_v='Trimmed_ACSM2_10cycles1.trc' % [ID '.trc'];
TargetPower=input('Type in Target Power: ');
% CL=0.17; %crank length used for torque calculations
BW=input('Type in body weight in kg: ');
age=input('Type in age in years: ');


analog=dlmread(filename_a,'\t',11,0');
video=dlmread(filename_v,'\t',6,0');


% Antwand, post wand, 5th met, lat mal, Lat epicondyle
   yr = -video(:,[33,36,30, 24, 15, 6, 3 ]); % specific to Joao's marker set (y needed to be multiplied by -1 to reflect taht positive y
is forward)
   zr = video(:,[34,37,31,25,16,7,4]); % note these are the x data in the trc files

   Ftangential=-(analog(:,2)+analog(:,3))*0.0082 + 0.828; % Owen calibration new system June 2014
   Fnormal=(analog(:,4)+analog(:,5))*0.0346 - 0.5006; % Owen calibration new system June 2014


yr = yr/1000;      zr = zr/1000;    % convert to m units


% filter Force data with butterworth filter 2nd order reverse filtering for no phase lag
[B,A] = butter(2,20/960); % 2nd order butterworth filter sets cutoff at 20 Hz, sampling frequency = 960Hz
FTfilt(:,1)=filtfilt(B,A,Ftangential(:)); % filtfilt: zero phase lag
FNfilt(:,1)=filtfilt(B,A,Fnormal(:));



% filter coordinate data
clear B A
for j=1:7
   [B,A] = butter(2,10/120); % 2nd order, 10Hz cutoff,
   y(:,j) = filtfilt(B,A,yr(:,j));
   z(:,j) = filtfilt(B,A,zr(:,j));
end
% downsample force data
down=(1:8:length(analog(:,1)))';
FyFiltDown(:,1)=-FTfilt(down);
FzFiltDown(:,1)=FNfilt(down);




for i=1:length(z(:,1))
%    wandlength(i)=sqrt((z(i,2)^2+z(i,1)^2));
   zc(i,1)=z(i,1)+0.5*(z(i,2)-z(i,1));
   yc(i,1)=y(i,1)+0.5*(y(i,2)-y(i,1));
end
```

```
%%----------------------------------------------------------------------
%% determines the dead top center of the pedal action
%%----------------------------------------------------------------------
r=0;
for m = 1:length(y)-3
    if ((zc(m+1,1) - zc(m,1))*(zc(m+2,1)-zc(m+1,1)) < 0) & (zc(m+1,1)>.3|(zc(m+1,1)>0 & zc(m+1,1)<.2))
        r=r+1;
        t(r,1)=m+1;
   end
end
f=1; %f is defining the index for the vector (top)
f2=1; %f2 is defining the index for the vector bot
for u = 1:r;
    if zc(t(u,1),1) - zc(t(u,1)+2,1) > 0;
    top(f,1) = t(u,1);          % frames for top dead center
    f=f+1;
    else
    bot(f2,1) = t(u,1);         % frames for bottom dead center
    f2=f2+1;
    end %if
end %for

%%----------------------------------------------------------------------
% calculate values for 90 degrees and 270 for calculation of crank center
%%----------------------------------------------------------------------
r=0;
for m = 1:length(y)-3
    if ((yc(m+1,1) - yc(m,1))*(yc(m+2,1)-yc(m+1,1)) < 0) %
        r=r+1;
        ty(r,1)=m+1;
    end
end
f=1; %f is defining the index for the vector (top)
f2=1; %f2 is defining the index for the vector bot
for u = 1:r;
    if yc(ty(u,1),1) - yc(ty(u,1)+2,1) > 0;
        max90(f,1) = ty(u,1);           % frames for top dead center
        f=f+1;
    else
        max270(f2,1) = ty(u,1);         % frames for bottom dead center
        f2=f2+1;
    end %if
end %for
% now calculate the actual RPM which was achieved
for i=1:length(top)-1
   %first RPM
   RPM(i,1)=7200/(top(i+1,1)-top(i,1));
end

%%----------------------------------------------------------------------
% calculate crank axis of rotation
%%----------------------------------------------------------------------
difCRANKz=(zc(top(1:10,1),1)+zc(bot(1:10,1),1))/2;
CRANKz=mean(difCRANKz);
difCRANKy=(yc(max90(1:10,1),1)+yc(max270(1:10,1),1))/2;
CRANKy=mean(difCRANKy);
count=0;

%%----------------------------------------------------------------------
% calculate pedal and crank angle ---------------------------------------
%%----------------------------------------------------------------------
clear r c
[r,c]=size(y);
L=min(r,length(FyFiltDown));


for s=1:L
    clear cranklength
    % pedal angle use pedal wand marker
    yy(s,1) = y(s,1) - y(s,2); % +ve for y ped
    zz(s,1) = z(s,1) - z(s,2); % +ve if ant marker is above post marker =dorsi flex
    segl(s,1) = sqrt((y(s,2) - y(s,1))^2 + (z(s,2) - z(s,1))^2);
    thetaped(s,1) = asin(zz(s,1)/segl(s,1)); % PEDAL ANGLE in radians
```

```
  % crank angle
  yy(s,2)=yc(s,1)-CRANKy;
  zz(s,2)=zc(s,1)-CRANKz;
  segl(s,2)=sqrt(yy(s,2)^2+zz(s,2)^2);
  thetacrank(s,1)=asin(yy(s,2)/segl(s,2));
  %by default the value for the angle is in quadrant 1, so consider the cases in quadrant 2 3 4
  if zz(s,2)<0 & yy(s,2)>0 % crank in 2nd quadrant
    thetacrank(s,1)=pi-thetacrank(s,1); %here thetacrank positive so subtract theta from 180 deg
  elseif zz(s,2)<0 & yy(s,2)<0
    thetacrank(s,1)=pi-thetacrank(s,1); %in this case thetacrank negative so sum up 2 positive numbers
  elseif zz(s,2)>0 & yy(s,2)<0 & s>1 & s<r-1 & ~(zc(s,1)>zc(s+1,1)&zc(s,1)>zc(s-1,1))
    thetacrank(s,1)=2*pi+thetacrank(s,1); % in this case thetacrank negative so subtract it from 360 deg
  end
  if s>1 & thetacrank(s,1)<0.5*pi & thetacrank(s-1,1)>1.5*pi % this procedure creates a strictly increasing crank angle
                                                  % introduced to get a continous crank angular velocity
      count=count+1; %initial condition for count =0
  end



   thetacranklin(s,1)=count*2*pi+thetacrank(s,1); % thetacranklin is a strictly increasing function of time approaching
                                   % a line with the slope equal to average velocity (RPM)



  % transfer pedal force into intertial reference frame
%    Fhorizontal(s,1)=cos(thetaped(s,1))*FyFiltDown(s)-sin(thetaped(s,1))*FzFiltDown(s);
%    Fvertical(s,1)=sin(thetaped(s,1))*FyFiltDown(s)+cos(thetaped(s,1))*FzFiltDown(s); % Fz1 vertical force in inertial frame

Fhorizontal(s,1)=cos(thetaped(s,1))*FyFiltDown(s)-sin(thetaped(s,1))*FzFiltDown(s);
Fvertical(s,1)=sin(thetaped(s,1))*FyFiltDown(s)+cos(thetaped(s,1))*FzFiltDown(s); % Fz1 vertical force in inertial frame

end

cranklength=mean(segl(:,2));

for s=1:L


% transfer pedal force into crank reference frame and calculate torque by multiplying with crank length
  FCrankTangential(s,1)=cos(thetacrank(s,1))*Fhorizontal(s,1)-sin(thetacrank(s,1))*Fvertical(s,1); %force tangential to crank
  FCrankRadial(s,1)=cos(thetacrank(s,1))*Fvertical(s,1)+sin(thetacrank(s,1))*Fhorizontal(s,1); %force tangential to crank
  %CrankTorque(s,1)=-FCrankTangential(s,1)*0.17; %cranklength; %segl(s,2);
  Fresultant1(s,1)=sqrt(FCrankTangential(s,1)^2+FCrankRadial(s,1)^2);
  Fresultant2(s,1)=sqrt(Fhorizontal(s,1)^2+Fvertical(s,1)^2);


end %s loop

for s=1:L
    CrankTorque(s,1)=-FCrankTangential(s,1)*mean(segl(:,2));
if s>1 & thetacranklin(s,1)-thetacranklin(s-1)>6
   thetacranklin(s:L,1)=thetacranklin(s:L,1)-2*pi;
end
end

plot(thetacranklin); pause; clf


% calculate crank angular velocity in rad/s
thetacrankvel(:,1)=diff(thetacranklin(:,1))/(1/120);
% calculate external power as the product of crank angular velociy and the torque
for s=1:min(r,length(FyFiltDown))-1
  ExtPower(s,1)=thetacrankvel(s,1)*CrankTorque(s,1);
end
% calculate average powers and indeces of force effectiveness
for i=1:min(length(bot),length(top))-1
  AveragePower(i,1)=mean(ExtPower(top(i,1):top(i+1,1)-1));

%    IE360(i-1)=100*trapz(-FCrankTangential(top(i,1):top(i+1,1)-1))/trapz(Fresultant1(top(i,1):top(i+1,1)-1));
%    end_interval=round(top(i,1)+.5*(top(i+1)-top(i)));
%    IE180(i-1)=100*trapz(-FCrankTangential(top(i,1):end_interval))/trapz(Fresultant1(top(i,1):end_interval));
end
```

```
for i=1:length(top)-1
 plot(ExtPower(top(i,1):top(i+1,1)-1)); hold on;
end
title('Power Profiles'); pause; close



disp(['The total pedal power in Watts is ' num2str(mean(AveragePower))]);
disp(['The average RPM is ' num2str(mean(RPM))]);

% now identify the revolutions that meet the criteria (according to Korff & Jensen, 2007)
k=0;
for i=1:min(length(top),length(bot))-1
    if abs(65-RPM(i))<=5 & AveragePower(i)<TargetPower*0.575 & AveragePower(i)>TargetPower*0.425
        k=k+1;
        rev_index(k)=i;
    end
end

if k==0
    RPM
    AveragePower
    error('No revolutions meet the criteria')

end



disp(['A total of ' num2str(k) ' revolutions meet the inclusion criteria.']);




% % calculate shanklength and thigh length, so knee joint centre can be
% % reconstructed using law of cosines
% for s=1:r
%    %thigh length
%    yy(s,3) = y(s,4) - y(s,5); % +ve for y thigh defined from the hip to knee
%    zz(s,3) = z(s,5) - z(s,4); % +ve for z thigh defined from the hip to knee
%    segl(s,3) = sqrt(yy(s,3)^2 + zz(s,3)^2);
%    %shank length
%    yy(s,4) = y(s,4) - y(s,3); % +ve for y shank
%    zz(s,4) = z(s,4) - z(s,3); % +ve for z shank
%    segl(s,4) = sqrt(yy(s,4)^2 + zz(s,4)^2);
%    % 5/8/03 this won't be used any more, but the term y(s,4)-y(s,6) will be used to estimate foot COG
%    yy(s,5) = y(s,1)-y(s,3); % toe-ankle +positive
%    zz(s,5) = z(s,1)-z(s,3); % negative for plantarflexed
%    segl(s,5)=sqrt(yy(s,5)^2 + zz(s,5)^2);
%
% end %s loop
%
% thighlength=mean(segl(:,3));
% shanklength=mean(segl(:,4));
% footlength=mean(segl(:,5));
%
% % Calculate new knee joint centre using the law of cosines. This is
% % appropriate because the sum of joint powers will add up to 100% of total
% % mechancial power
% for s=1:r
%     ha_length(s)=sqrt((z(s,3)-z(s,5))^2+(y(s,3)-y(s,5))^2);
%     zz_ah(s)=z(s,5)-z(s,3);
%     yy_ah(s)=y(s,5)-y(s,3);
%     alpha(s)=acos((ha_length(s)^2+thighlength^2-shanklength^2)/(2*ha_length(s)*thighlength));
%     delta(s)=acos(zz_ah(s)/ha_length(s));
%     zz_hk(s)=thighlength*cos(delta(s)+alpha(s));
%     yy_hk(s)=thighlength*sin(delta(s)+alpha(s));
% end

% for s=1:r
%     z(s,4)=z(s,5)-zz_hk(s);
%     y(s,4)=y(s,5)+yy_hk(s);
% end
```

```
%%-----------------------------------------------------------------------
% calculate segment angles
%%-----------------------------------------------------------------------
%% According to Neptune and Hull, 1995, the Hip Joint Center can be well estimated and with less error
%% using an ASIS reference, except in cases where the pelvis rotates considerably.
%% The vector from the average position of the greater trochanter and ASIS marker is determined


mny6 = mean(y(1:L,6)); % y GRT
mnz6 = mean(z(1:L,6)); % z GRT
mny7 = mean(y(1:L,7)); % y ASIS
mnz7 = mean(z(1:L,7)); % z ASIS
yhjc(1:L,1)=y(1:L,7)+(mny6-mny7);
zhjc(1:L,1)=z(1:L,7)+(mnz6-mnz7);
clear mny6 mnz6 mny7 mnz7

%%-----------------------------------------------------------------------
% calculate segment angles
%%-----------------------------------------------------------------------
clear r c
[r,c]=size(y);
for s=1:min(r,length(FyFiltDown))
   %thigh angle
   yy(s,3) = y(s,5) - yhjc(s,1); % +ve for y thigh defined from the hip to knee
   zz(s,3) = zhjc(s,1) - z(s,5);    % +ve for z thigh defined from the hip to knee
   segl(s,3) = sqrt(yy(s,3)^2 + zz(s,3)^2);
   % defines angle from positive horizontal (y) to thigh
   thetathigh(s,1) = pi-(asin(zz(s,3)/segl(s,3)));
   thetathigh1(s,1) = (asin(zz(s,3)/segl(s,3)));

   %shank angle
   yy(s,4) = y(s,5) - y(s,4);   % +ve for y shank
   zz(s,4) = z(s,5) - z(s,4);   % +ve for z shank
   segl(s,4) = sqrt(yy(s,4)^2 + zz(s,4)^2);
   % absolute shank ANGLE in radians
   thetashank(s,1) = acos(yy(s,4)/segl(s,4));

   % foot angle
   yy(s,5) = y(s,3)-y(s,4); % toe-ankle +positive
   zz(s,5) = z(s,3)-z(s,4); % negative for plantarflexed
   segl(s,5)=sqrt(yy(s,5)^2 + zz(s,5)^2);
   thetafoottemp(s,1)=asin((zz(s,5)/segl(s,5)));
   %thetafoottemp(s,1)=atan((zz(s,5)/yy(s,5)));
   if thetafoottemp(s,1)>1.0
      thetafoot(s,1)=-thetafoottemp(s,1);
   else
      thetafoot(s,1)=thetafoottemp(s,1);
   end
end %s loop

CL=mean(segl(:,2))
thighlength=mean(segl(:,3));
shanklength=mean(segl(:,4));
footlength=mean(segl(:,5));



%%-----------------------------------------------------------------------
% anthropometric characteristics using Jensen (1989)
%%-----------------------------------------------------------------------
age=20;
SCfoot=0.01335+0.0014661*age-0.000071030*age^2;
SCshank=0.02177+0.0048532*age-0.00019003*age^2;
SCthigh=0.04309+0.0088978*age-0.00027425*age^2;
mf=SCfoot*BW;
ms=SCshank*BW;  % mass of shank segment
mt=SCthigh*BW; % mass of thigh segment
rc1=0.5; % this value is taken from Winter via Dempster via Miller & Nelson - Winter is clearer about how to
         % estimate the foot COG location (ankle - 5th metartasal phalangeal joint (estimated by pedal marker))
         % note that the moment of inertia of the foot will still be estimated using Jensen (1989)
rc2=0.44429-0.0021059*age; % distance from knee to COG of shank segment
rc3=0.446090; % distance from hip to COG of thigh segment
rc3=.433;
rgfoot=0.24370; % radii of gyration Jensen (1989) p. 532
```

```
rgshank=0.29271-0.00067104*age;
rgthigh=0.29090;
yCOGfoot=y(1:L,4)+rc1*(y(1:L,3)-y(1:L,4)); %
zCOGfoot=z(1:L,4)+rc1*(z(1:L,3)-z(1:L,4)); % Winter: 1st edition p.150
yCOGshank=y(1:L,5)+rc2*(y(1:L,4)-y(1:L,5)); % y(:,5): knee; y(:,4): ankle
zCOGshank=z(1:L,5)+rc2*(z(1:L,4)-z(1:L,5)); % z(:,5): knee; z(:,4): ankle
yCOGthigh=yhjc(1:L,1)+rc3*(y(1:L,5)-yhjc(1:L,1)); % y(:,5): knee;
zCOGthigh=zhjc(1:L,1)+rc3*(z(1:L,5)-zhjc(1:L,1)); % z(:,5): knee;
Is=ms*(shanklength*rgshank)^2; % shank moment of inertia
It=mt*(thighlength*rgthigh)^2; % thigh moment of inertia
If=mf*(footlength*rgfoot)^2; % footlength is heel to longest toe

% ------------------------------------------------------------------------------------------------------------------------------
% calculate velocities using Woltring (1985) procedure calls gcvspl.dll and splder.dll current directory needs to be: work/diss
% ------------------------------------------------------------------------------------------------------------------------------
clear L
thetaANKLE=thetashank-thetafoot;
AV=[thetathigh1 thetashank thetafoot thetaped thetaANKLE yhjc(:,1) zhjc(:,1)];
X=(1/120)*[1:r]'; %define vector for time axis; r is number of rows
NY=r; % r was defined as the number of rows earlier
WX(1:r)=1; % set up a vector of length j that just contains 1 --> no weights for rows
WY(1:11)=1; % define a vector of length 9 that just contains 1 --> no weights for columns
M=2; % cubic
N=r; %      N       ( I )   Number of observations per dataset, with N.ge.2*M.
K=7; % # of columns
MD=2; % optimizes algorithm
VAL=1; %I think val is a value to optimize the algorithm
NC=r; %omptimzes algorithm
% apply GCVSPL routine calls gcvspl.dll
[C, W, IER] = gcvspl( X, AV, NY, WX, WY, M, N, K, MD, VAL, NC);
% now apply splder routine calls splder.dll
IDER=1; % # of derivative 1: velocity
M=2; % cubic spline T is the point in time where derivative is taken; X is time domain here
L=r; % I think this is a value to optimize the algorighm
for j=1:7
for i=1:r-1
T=i/120; % go up in increments of 1/120 s
[SVIDER] = splder ( IDER, M, r, T, X, C(:,j), L, W);
AVdiff(i,j)=SVIDER;
end
AVdiff(:,j);
end %j loop
omegaTHIGH=AVdiff(:,1);
omegaSHANK=AVdiff(:,2);
omegaFOOT=AVdiff(:,3);
omegaPED=AVdiff(:,4);
omegaANKLE=AVdiff(:,5);
y_hip_vel=AVdiff(:,6);
z_hip_vel=AVdiff(:,7);

% AV=[thetathigh1 thetashank thetafoot thetaped thetaANKLE yhjc(:,1) zhjc(:,1)];
%
% omegaTHIGH=diff(thetathigh1)/(1/120);
% omegaSHANK=diff(thetashank)/(1/120);
% omegaFOOT=diff(thetafoot)/(1/120);
% omegaPED=diff(thetaped)/(1/120);
% omegaANKLE=diff(thetaANKLE)/(1/120);
% y_hip_vel=diff(yhjc(:,1))/(1/120);
% z_hip_vel=diff(zhjc(:,1))/(1/120);



omegaKNEE=omegaTHIGH+omegaSHANK;


% ------------------------------------------------------------------------------------------------------------------------------
% calculate accelerations using Woltring (1985) procedure calls gcvspl.dll and splder.dll current directory needs to be: work/diss
% ------------------------------------------------------------------------------------------------------------------------------
% calculate velocities and accelerations
clear SVIDER C AVdiff deltat NY WX WY M N K MD VAL NC A AV L
A=[yCOGfoot zCOGfoot yCOGshank zCOGshank yCOGthigh zCOGthigh thetaped thetafoot thetashank thetathigh1];
X=(1/120)*[1:r]'; %define vector for time axis; r is number of rows
NY=r; % r was defined as the number of rows earlier
WX(1:r)=1; % set up a vector of length j that just contains 1 --> no weights for rows
WY(1:11)=1; % define a vector of length 9 that just contains 1 --> no weights for columns
```

```
M=2; % cubic
N=r; %      N       ( I )   Number of observations per dataset, with N.ge.2*M.
K=10; % # of columns
MD=2; % optimizes algorithm
VAL=1; %I think val is a value to optimize the algorithm
NC=r; %omptimzes algorithm
% apply GCVSPL routine calls gcvspl.dll
[C, W, IER] = gcvspl( X, A, NY, WX, WY, M, N, K, MD, VAL, NC);
% now apply splder routine calls splder.dll
IDER=2; % # of derivative
M=2; % cubic spline T is the point in time where derivative is taken; X is time domain here
L=r; % I think this is a value to optimize the algorighm
for j=1:10
for i=1:r-1
T=i/120; % go up in increments of 1/120 s
[SVIDER] = splder ( IDER, M, r, T, X, C(:,j), L, W);
Adiff(i,j)=SVIDER;
end
Adiff(:,j);
end %j loop

ACCyCOGfoot=Adiff(:,1);
ACCzCOGfoot=Adiff(:,2);
ACCyCOGshank=Adiff(:,3);
ACCzCOGshank=Adiff(:,4);
ACCyCOGthigh=Adiff(:,5);
ACCzCOGthigh=Adiff(:,6);
alphaPED=Adiff(:,7);
alphaFOOT=Adiff(:,8);
alphaSHANK=Adiff(:,9);
alphaTHIGH=Adiff(:,10);




% -----------------------------------------------------------------------------------
% Big s-loop which calculates reaction forces and net moments
% -----------------------------------------------------------------------------------
% now apply rotation cosine matrix
L=min(r,length(FyFiltDown));
for s=1:L-2
Fy1(s)=Fhorizontal(s,1); % horizontal pedal reaction force
Fz1(s)=Fvertical(s,1); % vertical pedal reaction force

% Calculate joint reaction forces and momment at ankle joint
Fy2(s)=mf*ACCyCOGfoot(s)-Fy1(s);                % Fy2 is the y component of the reaction force at the ankle
                                                % and is defined in the positive y-direction Winter (1990, p.81)
Fz2(s)=mf*9.81+mf*ACCzCOGfoot(s)-Fz1(s);    % Fz2 is the z component of the reaction force at the ankle
                                                % and is defined in the positive z-direction Winter (1990, p.81)

M1n(s)=+Fz2(s)*(yCOGfoot(s)-y(s,4))-Fy2(s)*(zCOGfoot(s)-z(s,4))...
    -Fz1(s)*(y(s,3)-yCOGfoot(s))+Fy1(s)*(z(s,3)-zCOGfoot(s))...
    +If*alphaFOOT(s,1);

M1(s)=-Fz1(s)*(y(s,3)-yCOGfoot(s))-Fy1(s)*(zCOGfoot(s)-z(s,3))...
   +Fz2(s)*(yCOGfoot(s)-y(s,4))+Fy2(s)*(z(s,4)-zCOGfoot(s))+If*alphaFOOT(s); % ankle moment
% this assumes that the pedal marker is the point of force application
AnklePower(s)=omegaANKLE(s)*M1(s);


% Calculate joint reaction forces and momment at knee joint
Fy3(s)=Fy2(s)+ms*ACCyCOGshank(s); %Fy3: joint reaction force at knee joint; positive y direction
Fz3(s)=Fz2(s)+ms*9.81+ms*ACCzCOGshank(s); %Fz3: joint reaction force at knee joint; positive z direction

M2(s)=M1(s)-Fz3(s)*(y(s,5)-yCOGshank(s))+Fy3(s)*(z(s,5)-zCOGshank(s))...
 +(-Fz2(s))*(yCOGshank(s)-y(s,4))-(-Fy2(s))*(zCOGshank(s)-z(s,4))+Is*alphaSHANK(s); % M2: net moment at knee joint +ve:
extensor moment
KneePower(s)=omegaKNEE(s)*M2(s);

% Calculate joint reaction forces and net moment
Fy4(s)=Fy3(s)+mt*ACCyCOGthigh(s); %Fy4: joint reaction force at hip joint; positive y direction
Fz4(s)=Fz3(s)+mt*9.81+mt*ACCzCOGthigh(s); %Fz4: joint reaction force at hip joint; positive z direction

% M3(s)=M2(s)+Fz4(s)*(yCOGthigh(s)-y(s,5))+Fy4(s)*(z(s,5)-zCOGthigh(s))-(-Fz3(s))*(y(s,4)-yCOGthigh(s))...
%    -(-Fy3(s))*(zCOGthigh(s)-z(s,4))+It*alphaTHIGH(s);
```

```
M3(s)=M2(s)-Fz4(s)*(yhjc(s,1)-yCOGthigh(s))+Fy4(s)*(zhjc(s,1)-zCOGthigh(s))+(-Fz3(s))*(yCOGthigh(s)-y(s,5))...
   -(-Fy3(s))*(zCOGthigh(s)-z(s,5))+It*alphaTHIGH(s);



HipPower(s)=-omegaTHIGH(s)*M3(s);
HipTransferPower(s)=Fy4(s)*y_hip_vel(s)+Fz4(s)*z_hip_vel(s);
end

%---------------------------------------------------------------------------
%-------------------calculate Hip Extension and Flexion power-------------
%---------------------------------------------------------------------------
for i=1:length(top)-1
    k=0;HipExtPowerTemp=0; HipFlexPowerTemp=0; HipExtCount=0; HipFlexCount=0;
    while k<top(i+1)-top(i)
       if omegaTHIGH(top(i)+k)>0
          HipExtPowerTemp=HipExtPowerTemp+HipPower(top(i)+k);
          HipExtCount=HipExtCount+1;
      else
          HipFlexPowerTemp=HipFlexPowerTemp+HipPower(top(i)+k);
          HipFlexCount=HipFlexCount+1;
      end
          k=k+1;
    end
    AVHipExtPower(i)=HipExtPowerTemp/HipExtCount;
    AVHipFlexPower(i)=HipFlexPowerTemp/HipFlexCount;
    DutyCycleHip(i)=HipExtCount/HipFlexCount;
end

%---------------------------------------------------------------------------
%-------------------calculate Knee Extension and Flexion power-------------
%---------------------------------------------------------------------------
for i=1:length(top)-1
    k=0;KneeExtPowerTemp=0; KneeFlexPowerTemp=0;  KneeExtCount=0; KneeFlexCount=0;
    while k<top(i+1)-top(i)
       if omegaKNEE(top(i)+k)>0 % knee extension is positive
          KneeExtPowerTemp=KneeExtPowerTemp+KneePower(top(i)+k);
          KneeExtCount=KneeExtCount+1;
      else
          KneeFlexPowerTemp=KneeFlexPowerTemp+KneePower(top(i)+k);
          KneeFlexCount=KneeFlexCount+1;
      end
          k=k+1;
    end
    AVKneeExtPower(i)=KneeExtPowerTemp/KneeExtCount;
    AVKneeFlexPower(i)=KneeFlexPowerTemp/KneeFlexCount;
    DutyCycleKnee(i)=KneeExtCount/KneeFlexCount;
end

%---------------------------------------------------------------------------
%-------------------calculate Ankle Extension and Flexion power------------
%-----Flexion is plantarflexion; extension is dorsiflexion-----------------
%---------------------------------------------------------------------------
for i=1:length(top)-1
    k=0;AnkleExtPowerTemp=0; AnkleFlexPowerTemp=0;  AnkleExtCount=0; AnkleFlexCount=0;
    while k<top(i+1)-top(i)
       if omegaANKLE(top(i)+k)<0 % positive is Plantarflexion
          AnkleExtPowerTemp=AnkleExtPowerTemp+AnklePower(top(i)+k);
          AnkleExtCount=AnkleExtCount+1;
      else
          AnkleFlexPowerTemp=AnkleFlexPowerTemp+AnklePower(top(i)+k);
          AnkleFlexCount=AnkleFlexCount+1;
      end
          k=k+1;
    end
    AVAnkleExtPower(i)=AnkleExtPowerTemp/AnkleExtCount;
    AVAnkleFlexPower(i)=AnkleFlexPowerTemp/AnkleFlexCount;
    DutyCycleAnkle(i)=AnkleFlexCount/AnkleExtCount;
end


figure
for j=1:length(rev_index)
    i=rev_index(j);
```

```
MusPower=-AnklePower+KneePower+HipPower;
 plot(-AnklePower(top(i,1):top(i+1,1)),'b'); hold on;
 ti=['ankle power ' num2str((-100*mean(AnklePower(top(i,1):top(i+1,1)))/mean(ExtPower(top(i,1):top(i+1,1)))))];
title(ti);
 plot(KneePower(top(i,1):top(i+1,1)),'r'); hold on;
 ti=['knee power ' num2str((100*mean(KneePower(top(i,1):top(i+1,1)))/mean(ExtPower(top(i,1):top(i+1,1)))))];
title(ti);
 plot(HipPower(top(i,1):top(i+1,1)),'k'); hold on;
 ti=['hip power ' num2str((100*mean(HipPower(top(i,1):top(i+1,1)))/mean(ExtPower(top(i,1):top(i+1,1)))))];
title(ti);
 plot(HipTransferPower(top(i,1):top(i+1,1)),'m'); hold on;
 ti=['hip transfer power ' num2str((100*mean(HipTransferPower(top(i,1):top(i+1,1)))/mean(ExtPower(top(i,1):top(i+1,1)))))];
title(ti);
plot(MusPower(top(i,1):top(i+1,1)),'g'); hold on;
plot(ExtPower(top(i,1):top(i+1,1)),'k'); hold on;



sum_power(i)=100*mean(-AnklePower(top(i,1):top(i+1,1)))/mean(ExtPower(top(i,1):top(i+1,1)))+...
    100*mean(KneePower(top(i,1):top(i+1,1)))/mean(ExtPower(top(i,1):top(i+1,1)))+...
    100*mean(HipPower(top(i,1):top(i+1,1)))/mean(ExtPower(top(i,1):top(i+1,1)))+...
    100*mean(HipTransferPower(top(i,1):top(i+1,1)))/mean(ExtPower(top(i,1):top(i+1,1)));

ti=['sumpower=' num2str(sum_power(i))];
title({'Muscular(green) External(black) knee(red) ankle(blue) hip(black) hip-transfer(turqu)'; ti});
pause; close all

AV_ankle(i)=100*mean(-AnklePower(top(i,1):top(i+1,1)))/mean(ExtPower(top(i,1):top(i+1,1)));
AV_knee(i)=100*mean(KneePower(top(i,1):top(i+1,1)))/mean(ExtPower(top(i,1):top(i+1,1)));
AV_hip(i)=100*mean(HipPower(top(i,1):top(i+1,1)))/mean(ExtPower(top(i,1):top(i+1,1)));
AV_hiptrans(i)=100*mean(HipTransferPower(top(i,1):top(i+1,1)))/mean(ExtPower(top(i,1):top(i+1,1)));
max_ankle(i)=max((-AnklePower(top(i,1):top(i+1,1)))/mean(ExtPower(top(i,1):top(i+1,1))));
max_knee(i)=max((KneePower(top(i,1):top(i+1,1)))/mean(ExtPower(top(i,1):top(i+1,1))));
max_hip(i)=max((HipPower(top(i,1):top(i+1,1)))/mean(ExtPower(top(i,1):top(i+1,1))));


% plot(Fy1(top(i,1):top(i+1,1))); hold on; title('horizontal pedal force'); pause; clf
% plot(Fz1(top(i,1):top(i+1,1))); hold on; title('vertical pedal force'); pause; clf
% plot(zCOGthigh(top(i,1):top(i+1,1))); hold on; title('vertical thigh COM'); pause; clf
% plot(yCOGthigh(top(i,1):top(i+1,1))); hold on; title('horizontal thigh COM'); pause; clf
%     plot(CrankTorque(top(i,1):top(i+1,1))); hold on; title('crank torque'); pause; clf
%     plot(thetacrank(top(i,1):top(i+1,1))); hold on; title('crank angle'); pause; clf
end


figure
for j=1:length(rev_index)
    i=rev_index(j);
 plot(Fy2(top(i,1):top(i+1,1)),'b'); hold on;
  title('ankle horizontal reaction force');
end
pause; close all

figure
for j=1:length(rev_index)
    i=rev_index(j);
 plot(Fz2(top(i,1):top(i+1,1)),'r'); hold on;
  title('ankle vertical reaction force');
end
pause; close all

figure
for j=1:length(rev_index)
    i=rev_index(j);
 plot(Fy3(top(i,1):top(i+1,1)),'b'); hold on;
  title('knee horizontal reaction force');
end
pause; close all

figure
for j=1:length(rev_index)
    i=rev_index(j);
 plot(Fz3(top(i,1):top(i+1,1)),'r'); hold on;
  title('knee vertical reaction force');
```

```
end
pause; close all

figure
for j=1:length(rev_index)
    i=rev_index(j);
 plot(-M1(top(i,1):top(i+1,1)),'r'); hold on;
  title('ankle moment');
end
pause; close all

figure
for j=1:length(rev_index)
    i=rev_index(j);
 plot(M2(top(i,1):top(i+1,1)),'r'); hold on;
  title('knee moment');
 end
pause; close all


% now extract actual dependent variables
for j=1:length(rev_index)
  i=rev_index(j);
  MaxMKneeTemp(j)=max(M2(top(i,1):top(i+1,1))); % maximum knee extensor moment
  MinMKneeTemp(j)=min(M2(top(i,1):top(i+1,1))); % maximum knee flexor moment
  MaxMAnkleTemp(j)=max(-M1(top(i,1):top(i+1,1))); % maximum plantarflexor moment
  MaxFy2Temp(j)=max(Fy2(top(i,1):top(i+1,1))); % maximum anterioly directed ankle reaction force
  MinFy2Temp(j)=min(Fy2(top(i,1):top(i+1,1))); % maximum posterioly directed ankle reaction force
  MaxFz2Temp(j)=max(-Fz2(top(i,1):top(i+1,1))); % maximum compressive ankle reaction force
  MaxFy3Temp(j)=max(Fy3(top(i,1):top(i+1,1))); % maximum anterioly directed knee reaction force
  MinFy3Temp(j)=min(Fy3(top(i,1):top(i+1,1))); % maximum posterioly directed knee reaction force
  MaxFz3Temp(j)=max(-Fz3(top(i,1):top(i+1,1))); % maximum compressive knee reaction force
end

MaxMKneeAV=mean(MaxMKneeTemp(:)); % maximum plantarflexor moment
MinMKneeAV=mean(MinMKneeTemp(:)); % maximum knee extensor moment
MaxMAnkleAV=mean(MaxMAnkleTemp(:)); % maximum knee flexor moment
MaxFy2AV=mean(MaxFy2Temp(:)); % maximum anterioly directed ankle reaction force
MinFy2AV=mean(MinFy2Temp(:)); % maximum posterioly directed ankle reaction force
MaxFz2AV=mean(MaxFz2Temp(:)); % maximum compressive ankle reaction force
MaxFy3AV=mean(MaxFy3Temp(:)); % maximum anterioly directed knee reaction force
MinFy3AV=mean(MinFy3Temp(:)); % maximum posterioly directed knee reaction force
MaxFz3AV=mean(MaxFz3Temp(:)); % maximum compressive knee reaction force



for j=1:length(rev_index)
    i=rev_index(j);
    PedPower61(:,i)=resample(ExtPower(top(i):top(i+1)-1), 60, top(i+1)-top(i)-1);
    MAnkle61(:,i)=resample(M1(top(i):top(i+1)-1), 60, top(i+1)-top(i)-1)'; % Ankle Moment
    MKnee61(:,i)=resample(M2(top(i):top(i+1)-1), 60, top(i+1)-top(i)-1)'; % Knee Moment
    Fy2_61(:,i)=resample(Fy2(top(i):top(i+1)-1), 60, top(i+1)-top(i)-1)'; % horizontal ankle reaction force
    Fz2_61(:,i)=resample(Fz2(top(i):top(i+1)-1), 60, top(i+1)-top(i)-1)'; % vertical ankle reaction force
    Fy3_61(:,i)=resample(Fy3(top(i):top(i+1)-1), 60, top(i+1)-top(i)-1)'; % horizontal knee reaction force
    Fz3_61(:,i)=resample(Fz3(top(i):top(i+1)-1), 60, top(i+1)-top(i)-1)'; % vertical knee reaction force
end



for i=1:61
     PedPower61AV(i)=mean(PedPower61(i,:));
     MAnkle61AV(i)=mean(MAnkle61(i,:));
     MKnee61AV(i)=mean(MKnee61(i,:));
     Fy2_61AV(i)=mean(Fy2_61(i,:)); % horizontal ankle reaction force
     Fz2_61AV(i)=mean(Fz2_61(i,:)); % vertical ankle reaction force
     Fy3_61AV(i)=mean(Fy3_61(i,:)); % horizontal knee reaction force
     Fz3_61AV(i)=mean(Fz3_61(i,:)); % vertical knee reaction force
 end

% ------------------------------------------------------------------------------------------
% write data in two separate outputfiles
% ------------------------------------------------------------------------------------------
% -----------------------------------------------------------------
% write data into outputfile ---------------------------------------
% -----------------------------------------------------------------
```

```
outfile1=[ID '_force_moment_data.txt'];
fid = fopen(outfile1,'a+');

for i=1:length(rev_index)
fprintf(fid,'%15s%15s%15s%15s%15s%15s','Ank_Mom','Knee_Mom','Ankle_Fy','Ankle_Fz','Knee_Fy','Knee_Fz');
end
fprintf(fid,'\n');
for i=1:length(rev_index)
fprintf(fid,'%15s%15s%15s%15s%15s%15s',num2str(rev_index(i)),num2str(rev_index(i)),num2str(rev_index(i)),num2str(rev_ind
ex(i)),num2str(rev_index(i)),num2str(rev_index(i)));
end
fprintf(fid,'\n');

for i=1:61
for k=1:length(rev_index)
   j=rev_index(k);

fprintf(fid,'%15.4f%15.4f%15.4f%15.4f%15.4f%15.4f',...
       MAnkle61(i,j),MKnee61(i,j),Fy2_61(i,j),...
       Fz2_61(i,j),Fy3_61(i,j),Fz3_61(i,j));
end
   fprintf(fid,'\n');
end


fclose all;


MaxMKneeAV=mean(MaxMKneeTemp(:)); % maximum plantarflexor moment
MinMKneeAV=mean(MinMKneeTemp(:)); % maximum knee extensor moment
MaxMAnkleAV=mean(MaxMAnkleTemp(:)); % maximum knee flexor moment
MaxFy2AV=mean(MaxFy2Temp(:)); % maximum anterioly directed ankle reaction force
MinFy2AV=mean(MinFy2Temp(:)); % maximum posterioly directed ankle reaction force
MaxFz2AV=mean(MaxFz2Temp(:)); % maximum compressive ankle reaction force
MaxFy3AV=mean(MaxFy3Temp(:)); % maximum anterioly directed knee reaction force
MinFy3AV=mean(MinFy3Temp(:)); % maximum posterioly directed knee reaction force
MaxFz3AV=mean(MaxFz3Temp(:)); % maximum compressive knee reaction force

output=[mean(RPM(rev_index)) mean(AveragePower(rev_index)) length(rev_index) MaxMKneeAV MinMKneeAV
MaxMAnkleAV MaxFy2AV MinFy2AV MaxFz2AV MaxFy3AV MinFy3AV MaxFz3AV];

clear fid

outfile2=['summary_data.txt'];

e=exist(outfile2);
if e==0
    fid = fopen(outfile2,'a+');

fprintf(fid,'%15s%15s%15s%15s%15s%15s%15s%15s%15s%15s%15s%15s%15s','ID','RPM','Ext_Power','#_rev','M_Knee_Ex
t','M_Knee_Flex','M_Plantar',...
   'Ank_anter','Ank_poster','Ank_Comp','Knee_anter','Knee_poster','Knee_Comp');
   fprintf(fid,'\n');
   fprintf(fid,'%15s%15.4f%15.4f%15.4f%15.4f%15.4f%15.4f%15.4f%15.4f%15.4f%15.4f%15.4f%15.4f',...
   ID,output(1),output(2),output(3),output(4),output(5),output(6),output(7),output(8),...
   output(9),output(10),output(11),output(12));
   fprintf(fid,'\n');
   fclose all;
else
  fid = fopen(outfile2,'a+');
  fprintf(fid,'%15s%15.4f%15.4f%15.4f%15.4f%15.4f%15.4f%15.4f%15.4f%15.4f%15.4f%15.4f%15.4f',...
   ID,output(1),output(2),output(3),output(4),output(5),output(6),output(7),output(8),...
   output(9),output(10),output(11),output(12));
   fprintf(fid,'\n');
   fclose all;
end % if
```

Appendix XIX: Reliability Analysis

R Knee Moment

Participant 1

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Vertical Peak value						
Average of 5 gait cycles	0.0402	0.0665	0.0583	0.0134	0.0550	**0.2445**
Average of 10 gait cycles	0.0398	0.0700	0.0538	0.0151	0.0545	**0.2769**

Participant 2

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Vertical Peak value						
Average of 5 gait cycles	0.1240	0.1800	0.1407	0.0287	0.1482	**0.1939**
Average of 10 gait cycles	0.4113	0.1597	0.1444	0.1499	0.2385	**0.6284**

Participant 3

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Vertical Peak value						
Average of 5 gait cycles	0.2140	0.2170	0.2314	0.0093	0.2208	**0.0420**
Average of 10 gait cycles	0.2673	0.2324	0.2324	0.0202	0.2440	**0.0827**

R Knee Reaction Force

Participant 1

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Vertical Reaction Force						
Average of 5 gait cycles	0.1078	0.3308	0.0382	0.1528	0.1589	**0.9618**
Average of 10 gait cycles	0.8998	0.2564	0.2220	0.3818	0.4594	**0.8310**

Participant 2

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Vertical Reaction Force						
Average of 5 gait cycles	0.1078	0.4340	0.3723	0.1733	0.3047	**0.5688**
Average of 10 gait cycles	1.2549	0.4410	0.3308	0.5047	0.6756	**0.7471**

Participant 3

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Vertical Reaction Force						
Average of 5 gait cycles	0.3523	0.7062	0.0239	0.3412	0.3608	**0.9458**
Average of 10 gait cycles	0.1316	0.5167	0.0369	0.2541	0.2284	**1.1126**

R Knee Horizontal Reaction Force

Participant 1

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Maximum Horizontal Reaction Force						
Average of 5 gait cycles	3.5735	3.7153	3.3334	0.1931	3.5407	**0.0545**
Average of 10 gait cycles	4.2736	3.6905	3.5448	0.3857	3.8363	**0.1005**

Participant 2

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Maximum Horizontal Reaction Force						
Average of 5 gait cycles	3.4824	3.7410	3.6545	0.1316	3.6260	**0.0363**
Average of 10 gait cycles	5.4129	5.5990	3.7423	1.0224	4.9181	**0.2079**

Participant 3

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Maximum Horizontal Reaction Force						
Average of 5 gait cycles	4.6616	2.7539	2.9372	1.0525	3.4509	**0.3050**
Average of 10 gait cycles	4.1795	2.8970	3.3699	0.6485	3.4822	**0.1862**

Participant 1

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Minimum Horizontal Reaction Force						
Average of 5 gait cycles	-3.9936	-4.5554	-3.8494	0.3730	-4.1328	**-0.0903**
Average of 10 gait cycles	-5.0691	-4.5735	-4.5892	0.2817	-4.7439	**-0.0594**

Participant 2

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Minimum Horizontal Reaction Force						
Average of 5 gait cycles	-3.9181	-3.8654	-3.8663	0.0302	-3.8833	**-0.0078**
Average of 10 gait cycles	-4.8080	-4.3801	-4.1422	0.3374	-4.4434	**-0.0759**

Participant 3

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Minimum Horizontal Reaction Force						
Average of 5 gait cycles	-5.5251	-3.7635	-4.1792	0.9208	-4.4893	**-0.2051**
Average of 10 gait cycles	-5.3606	-4.0545	-3.9893	0.7736	-4.4681	**-0.1731**

R Ankle Moment

Participant 1

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Vertical Peak value						
Average of 5 gait cycles	0.1990	0.3041	0.2273	0.0544	0.2435	**0.2234**
Average of 10 gait cycles	0.1999	0.3043	0.2219	0.0550	0.2420	**0.2274**

Participant 2

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Vertical Peak value						
Average of 5 gait cycles	0.0827	0.0748	0.0428	0.0211	0.0667	**0.3166**
Average of 10 gait cycles	0.0872	0.0714	0.0481	0.0197	0.0689	**0.2852**

Participant 3

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Vertical Peak value						
Average of 5 gait cycles	0.1957	0.1869	0.0493	0.0821	0.1440	**0.5704**
Average of 10 gait cycles	0.2303	0.2039	0.2067	0.0145	0.2136	**0.0680**

R Ankle Reaction Force

Participant 1

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Vertical Reaction Force						
Average of 5 gait cycles	-0.4183	-0.8135	-0.3490	0.2506	-0.5269	**-0.4755**
Average of 10 gait cycles	-0.2772	-0.3549	-0.3210	0.0390	-0.3177	**-0.1227**

Participant 2

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Vertical Reaction Force						
Average of 5 gait cycles	-0.4001	-0.4237	-0.3880	0.0182	-0.4039	**-0.0450**
Average of 10 gait cycles	0.4693	-0.4433	-0.4055	0.5163	-0.1265	**-4.0831**

Participant 3

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Vertical Reaction Force						
Average of 5 gait cycles	-0.3638	-0.3125	-0.5987	0.1526	-0.4250	**-0.3591**
Average of 10 gait cycles	-0.4728	-0.2975	-0.4991	0.1096	-0.4231	**-0.2590**

R Ankle Horizontal Reaction Force

Participant 1

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Maximum Horizontal Reaction Force						
Average of 5 gait cycles	3.3703	3.1882	3.3023	0.0920	3.2869	**0.0280**
Average of 10 gait cycles	3.3430	3.3478	3.2600	0.0494	3.3169	**0.0149**

Participant 2

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Maximum Horizontal Reaction Force						
Average of 5 gait cycles	3.3848	3.3060	3.4530	0.0736	3.3813	**0.0218**
Average of 10 gait cycles	3.8702	5.4416	3.5249	1.0216	4.2789	**0.2388**

Participant 3

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Maximum Horizontal Reaction Force						
Average of 5 gait cycles	3.6464	3.1875	3.1372	0.2806	3.3237	**0.0844**
Average of 10 gait cycles	3.4234	3.1720	3.1817	0.1424	3.2590	**0.0437**

Participant 1

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Minimum Horizontal Reaction Force						
Average of 5 gait cycles	-3.8694	-3.7204	-3.7337	0.0824	-3.7745	**-0.0218**
Average of 10 gait cycles	-3.8690	0.2522	-3.7141	2.3359	-2.4437	**-0.9559**

Participant 2

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Minimum Horizontal Reaction Force						
Average of 5 gait cycles	-3.6812	-3.8079	-3.8506	0.0881	-3.7799	**-0.0233**
Average of 10 gait cycles	-3.9982	-4.2194	-3.6854	0.2683	-3.9677	**-0.0676**

Participant 3

	Day 1	Day 2	Day 3	Std dev	Mean	Coefficient of Variation
Minimum Horizontal Reaction Force						
Average of 5 gait cycles	-3.5238	-3.3540	-3.4211	0.0855	-3.4330	**-0.0249**
Average of 10 gait cycles	-3.5871	-3.4680	-3.3363	0.1254	-3.4638	**-0.0362**

Appendix XX: Chapter 6. Participant information sheet

College of Health and Life Sciences
Department of Life Sciences

PARTICIPANT INFORMATION SHEET
Children's active commuting to school

Background and purpose of this study

You are being invited to participate in a study organised by researchers at Brunel University London. The purpose of the research is to explore motivations and experiences regarding active commuting to school in children. Exploring active commuting to school in children will bring insights and information such as what motivates children to walk or cycle to school. Such knowledge could help more children from other schools to find motivation and support to walk or cycle to school, which in turn could lead to more physical activity and a healthier lifestyle.

What will you have to do?

We will ask you questions about reasons to encourage your children to use public transportation, walk, cycle to school. The interview should not last longer than 30 minutes and it would be recorded for further analysis.

What are the benefits of taking part in this study?

You will learn about the importance of active commuting to school, i.e. walking or cycling to school. Results from this study can help your child to continue being physically active and other children to become more active.

What are the risks?

There are no risks for taking part in this study. You would be interviewed and answer a few questions lasting approximately 30 minutes. You do not need to change your routine take part in this study.

What if something goes wrong?

The person to be contacted if the participant wishes to complain about the experience should be the Chair of the principal investigator's College Research Ethics Committee. In CHLS this is Professor Christina Victor, Christina.Victor@brunel.ac.uk

What will happen to the results of the research study?

The results of this study will be presented in a doctoral thesis and published in an academic journal. We will also share the study results with participants and researchers at conferences.

Who is organising and funding the research?

The research is being organised by researchers from Brunel University London. The research team includes Mr João Greca who is a PhD researcher sponsored by the Brazilian federal government, Dr

Thomas Korff and Dr Jennifer Ryan, who are lecturers at the College of Health and Life Sciences at Brunel University London.

What are the indemnity arrangements?

Brunel University London holds insurance policies which apply to this study. If you can demonstrate that you experienced harm as a result of your participation in this study, you may be able to claim compensation. Please contact Prof Peter Hobson, the Chair of the University Research Ethics committee (Peter.hobson@brunel.ac.uk) if you would like further information about the insurance arrangements which apply to this study.

Who has reviewed the study?

This study has been reviewed and approved by the Research Ethics Committee of the College of Health and Life Sciences, Brunel University London.

Passage on Research Integrity

Brunel University is committed to compliance with the Universities UK Research Integrity Concordat. You are entitled to expect the highest level of integrity from our researchers during the course of their research.

Confidentiality

An identification code will be used for all participants. Neither you or your child's name nor any personal information will be stored with any data that will be collected. Only the investigators will be able to reconcile your results with your child's identity. Participant's quotes will be included in the results of the study and participants will be assigned pseudonyms. Any information that is obtained in connection with this study will remain confidential and will only be disclosed with your full permission.

Freedom to withdraw

Your participation is completely voluntary. Your decision whether or not to participate will not affect your relationship with Brunel University London. If you decide to participate, you are free to withdraw your approval for participation at any time without having to give any reasons and without penalty.

If you are interested in participating, or if you have any questions about this study, please **contact us** using the information below:

Mr João Greca
PhD Researcher
Tel: 07935 004054 || E-mail: Joao.DeAguiarGreca@brunel.ac.uk

Dr Jennifer Ryan
Lecturer in Physiotherapy
Tel: 01895 268702 || E-mail: Jennifer.Ryan@brunel.ac.uk

College of Health and Life Sciences
Department of Life Sciences

CONSENT FORM

STATEMENT

1. I agree to participate in this project;
2. I have read the Research Participant Information Sheet;
3. I had an opportunity to ask questions and discuss this study;
4. I understand that my child or I will not be referred to by name in any report concerning the study;
5. I understand that my participation is voluntary and that I may withdraw from the research at any time, without giving any reason. My decision not to participate will not alter the treatment that I would normally receive now or in the future;
6. I have received satisfactory answers to all my questions;
7. I agree to these results being used for educational and research purposes on the condition that my privacy is respected.

Participant's name: ____

Participant's signature: ____

Date: ____

	Yes	No
Are you happy with us taking pictures that might be used for scientific communications such as posters or power point presentations?	☐	☐
Are you interested in further studies, and if so are you happy for us to contact you?	☐	☐

E-mail address and/or telephone: ____

Appendix XXI: Chapter 6. Ethical approval

College of Health and Life Sciences Research Ethics Committee (DLS)
Brunel University London
Kingston Lane
Uxbridge
UB8 3PH
United Kingdom

www.brunel.ac.uk

8 August 2017

LETTER OF APPROVAL

Applicant: Mr Joao Greca

Project Title: Children's Active Commuting to School - Using Consent Forms

Reference: 7250-MHR-Jul/2017- 7949-1

Dear Mr Joao Greca

The Research Ethics Committee has considered the above application recently submitted by you.

The Chair, acting under delegated authority has agreed that there is no objection on ethical grounds to the proposed study. Approval is given on the understanding that the conditions of approval set out below are followed:

- D23 – PIS - On the information sheet it uses the phrase "if you and your child...". If just the parent is being interviewed then this should be revised accordingly to avoid confusion.
- D23 – PIS - Please also add a section Passage on the University's commitment to the UK Concordat on Research Integrity after the section 'Who has reviewed the study?' You have deleted it from the template.
- D23 – PIS - Please change the section on 'Contact for further information and complaints' to the text within the PIS template on the College Research Ethics IntraBrunel page at https://intra.brunel.ac.uk/chls/research/Pages/default.aspx# and add the contact for complaints to Professor Christina Victor, Chair College of Health and Life Sciences Research Ethics Committee, Christina.victor@brunel.ac.uk
- D23 – PIS - Please change the section on 'what are the indemnity arrangements' to the text within the PIS guidance on the College Research Ethics IntraBrunel page at https://intra.brunel.ac.uk/chls/research/Pages/default.aspx# removing the current text.
- D23 & D24 – PIS & Consent form - Please amend the headers using the template on the College Research Ethics IntraBrunel page at https://intra.brunel.ac.uk/chls/research/Pages/default.aspx# - you need both the College and the Department of life sciences on all forms, deleting Clinical Sciences.
- The agreed protocol must be followed. Any changes to the protocol will require prior approval from the Committee by way of an application for an amendment.

Please note that:

- Research Participant Information Sheets and (where relevant) flyers, posters, and consent forms should include a clear statement that research ethics approval has been obtained from the relevant Research Ethics Committee.
- The Research Participant Information Sheets should include a clear statement that queries should be directed, in the first instance, to the Supervisor (where relevant), or the researcher. Complaints, on the other hand, should be directed, in the first instance, to the Chair of the relevant Research Ethics Committee.
- Approval to proceed with the study is granted subject to receipt by the Committee of satisfactory responses to any conditions that may appear above, in addition to any subsequent changes to the protocol.
- The Research Ethics Committee reserves the right to sample and review documentation, including raw data, relevant to the study.
- You may not undertake any research activity if you are not a registered student of Brunel University or if you cease to become registered, including abeyance or temporary withdrawal. As a deregistered student you would not be insured to undertake research activity. Research activity includes the recruitment of participants, undertaking consent procedures and collection of data. Breach of this requirement constitutes research misconduct and is a disciplinary offence.

Professor Christina Victor

Appendix XXII: Preliminary questions for the interview guide

Themes and questions

- **Distance**

  How far is too far (in minutes and in kilometres)?

  Does distance matter for your child to walk alone outside?

  What would the minimum and maximum distances be?

- **Safety of your neighbourhood and social factors**

  Are there other travel modes for your child to get to school?

  Can your child walk or cycle outside in your neighbourhood at any time of the day?

  Do you think your child would be safer when walking, cycling or playing outside with friends?

  Is traffic safety a factor influencing your child transport mode?

- **Seasonal and socio-demographic determinants**

  Do seasons play a role on the way your child goes to school?

  Is winter a barrier for your child, or children in general, go walking or cycling to school?

  Do you think bike lanes would help children cycle more?

- **Age**

  How young is too young for a child to walk or cycle to school?

- **School facilities**

  Are there good and safe bicycle storages or a bicycle parking where your child study?

- **Solutions for more children to go to school cycling**

  What do you think about the idea of children cycling to get to their schools?

  Ecologically and environmentally speaking, what would contribute for more children go cycling to school?

Appendix XXIII: Interview guide used in data collection

Individual level

How does your child usually go to school?
(Prompts: walk, bus, car, bike? is it like this every day or almost every day? Why?)

What would your child's preferred method of getting to school be?
(Prompts: does he/she get to decide it? Does he/she go with friends?)

Social environment

Does your child go to school with friends?
(Prompts: what if they (or he/she) decided to use a bicycle to go to school?)

Environment level

Do you think it is safe for your child to walk alone outside?
(Prompts: at any time of the day, only for specific places and until certain distances)

What would be/are your greatest concerns about your child cycling to school?
(Prompts: is it the weather? Are the streets safe? Is it too far?)

Does your child's school offer a suitable place to keep bicycles?
(Prompts: would it make a difference for your child to cycle to school?)

Parental perspective

What are the reasons for choosing this way (walking, bus or car) to get to school?
(Prompts: weather, safety, distance)

Why does/doesn't your child cycle to school?
(Prompts: weather, security, distance)

What would have to change for your child to cycle to school?
(Prompts: distance from school, a place to lock the bicycle, weather conditions)

How realistic is it for your child to cycle to school?
(Prompts: why? Is there any specific reason for that?)

Do you think there are advantages/disadvantages to cycling to school?
(Prompts: would it be faster to go cycling to the school? Is it cycling healthier?)

Do you have anything else you want to say about using a bicycle to get to school?

Thank you for taking part in our study

Appendix XXIV: Random page of a transcribed interview

I: Ok, alright. Does she ever go to school with friends?

P: Ah, yes, they meet at the bus stop.

I: Ok, so from the bus stop?

P: Yes.

I: Alright, alright.

P: Not from where we live.

I: Do you think it is safe; Is there something concerning related to safety for [redacted] to walk outside alone? At any time of the day or?

P: Where we live, yes. Because, if she, she has her phone so we, would, coming from school or going (inaudible- 3.48). Well, usually both of us walk together because that would be my way to work so, we walk together but coming back sometimes… time changes so, it's different, so would walk, she has her phone and we're always in contact with each other, so yeah.

I: So, the telephone is an important item of security, and to feel safe?

P: Yes.

I: Would you consider also another point in safety such as the time of the day, the specific place, would you consider that some places wouldn't be safe around the school, you would consider distance to be related to safety?

P: Regarding the school right now, what I can say is that, she's starting on Friday. She's starting a new school, so that's a whole different thing I don't know as yet, but for the first week I will be taking her, to see how it is. So regarding those questions, regarding that school I can't answer you right now.

I: You can consider the previous school term to answer the question as we don't know much about the upcoming term yet

P: Yes, around the school and zone it's safe. There's one sort of little alley which would let in front of the school and with houses there, so, like, so she on one day she used to go a bit earlier to her music class, so it was a bit concerning about that. So, it's about two minutes when the bus drops her out to get to the entrance of the school so, first I used to tell her, once you drop off on the bus and she's passing through the alley and she don't have any friends with her you know, like, if there's no other children on the bus with her that time then you just run across. Make sure you call me when you get there, make sure you call me when you get to the school yard. So, that was kind, she would, once she get to the school yard, she would call me and say "Ok mama I'm in school now" and then I'm at least – Ok she's at school now, so it's alright.

I: Ok. So, you said something about being too early, and what time would you say that would be too early?

P: That used to be, he had to reach school at 8 o'clock in school, so, we're looking at about ten to eight something like that because we would walk all together and she would get her bus to school and I would get my bus to go to work so we, but, again we would be in contact over the phone, so ok I got my bus now you know that sort of thing.

I: Does your daughter's school offer a suitable place to keep the bike?

P: Yes, they had a place for bicycles, yes.

Appendix XXV: Codes generated after examining all interviews

1. Bus
2. Not having a car
3. Convenience
4. Distance
5. Walk
6. Commuting with friends
7. Quiet neighbourhood
8. Phone ownership
9. Keeping in contact
10. Parent accompanies
11. Safe neighbourhood
12. Unsafe
13. Time of the day
14. Bike park
15. Cold weather
16. Lack of companion
17. Enjoy cycling
18. Not suitable equipment
19. Lack of money
20. Riding outside
21. Going to town
22. Bike lock
23. No place to store the bike
24. Unsafe village
25. Safe neighbourhood
26. Physical activity day in school
27. Not suitable equipment
28. Bullying
29. Upsetting
30. Passion for riding
31. Harassment on the streets
32. Pavement not appropriate
33. Darkness
34. Winter
35. Busy road
36. Child’s age
37. Fear
38. Healthy choice
39. Public transportation
40. Difficult times
41. Parental concern with security
42. Learning to cycle
43. Spending time outside
44. Commuting with friends
45. Group of friends
46. Fitting with work

47. Staying in contact
48. Parent worried
49. Concerns about safety
50. Car
51. Cycling
52. Not willing
53. Decision maker
54. Child independence
55. Being mature
56. Too far to walk
57. Too early in the morning
58. Lack of public transportation
59. Nice weather
60. Intense traffic
61. Rainy days
62. Lack of encouragement
63. Convenient to cycle
64. Unsafe route
65. Heavy backpack
66. Off-roads
67. Cycling on the pavement
68. Risk of accidents
69. Help from parent's friends
70. Going to school with friends
71. Reasons to feel less concerned
72. Having friends
73. Child's environment preference
74. Physical activity encouragement
75. Risk of bullying
76. Discouragement from school
77. No place to park bikes
78. Discouragement from parents
79. Being active
80. Geographic barriers
81. Pavement improvement
82. Sharing the car
83. Frequency of commuting type
84. Child's lack of option
85. Sharing the car with friends
86. No security in neighbourhood
87. Parental concern
88. Afraid of people on streets
89. Distance prevents walking
90. Parental awareness regarding school's infrastructure
91. Convenient way for commuting
92. Health benefits
93. No place to park bikes
94. Fun

Appendix XXVI: Themes generated after examining all interviews

Themes

RESOURCES SAFETY ENVIRONMENT SOCIAL INFRASTRUCTURE PERCEIVED BENEFITS OF CYCLING

Codes

1. Bus
2. Not having a car
3. Convenience
4. Distance
5. Walk
6. Commuting with friends
7. Quiet neighbourhood
8. Phone ownership
9. Keeping in contact
10. Parent accompanies
11. Safe neighbourhood
12. Unsafe
13. Time of the day
14. Bike park
15. Cold weather
16. Lack of companion
17. Enjoy cycling
18. Not suitable equipment
19. Lack of money
20. Riding outside
21. Going to town
22. Bike lock
23. No place to store the bike
24. Unsafe village
25. Safe neighbourhood
26. Physical activity day in school
27. Not suitable equipment
28. Bullying
29. Upsetting
30. Passion for riding
31. Harassment on the streets
32. Pavement not appropriate
33. Darkness
34. Winter
35. Busy road
36. Child’s age
37. Fear
38. Healthy choice
39. Public transportation
40. Difficult times
41. Parental concern with security
42. Learning to cycle
43. Spending time outside
44. Commuting with friends

45. Group of friends
46. Fitting with work
47. Staying in contact
48. Parent worried
49. Concerns about safety
50. Car
51. Cycling
52. Not willing
53. Decision maker
54. Child independence
55. Being mature
56. Too far to walk
57. Too early in the morning
58. Lack of public transportation
59. Nice weather
60. Intense traffic
61. Rainy days
62. Lack of encouragement
63. Convenient to cycle
64. Unsafe route
65. Heavy backpack
66. Off-roads
67. Cycling on the pavement
68. Risk of accidents
69. Help from parent's friends
70. Going to school with friends
71. Reasons to feel less concerned
72. Having friends
73. Child's environment preference
74. Physical activity encouragement
75. Risk of bullying
76. Discouragement from school
77. No place to park bikes
78. Discouragement from parents
79. Being active
80. Geographic barriers
81. Pavement improvement
82. Sharing the car
83. Frequency of commuting type
84. Child's lack of option
85. Sharing the car with friends
86. No security in neighbourhood
87. Parental concern
88. Afraid of people on streets
89. Distance prevents walking
90. Parental awareness regarding school's infrastructure
91. Convenient way for commuting
92. Health benefits
93. No place to park bikes
94. Fun

Appendix XXVII: Random page demonstrating labels representing themes

I: Ok, alright. Does she ever go to school with friends?

P: Ah, yes, they meet at the bus stop.

I: Ok, so from the bus stop?

P: Yes.

I: Alright, alright.

P: Not from where we live.

I: Do you think it is safe; Is there something concerning related to safety for [redacted] to walk outside alone? At any time of the day or?

P: Where we live, yes. Because, if she, she has her phone so we, would, coming from school or going (inaudible- 3.48). Well, usually both of us walk together because that would be my way to work so, we walk together but coming back sometimes… time changes so, it's different, so would walk, she has her phone and we're always in contact with each other, so yeah.

I: So, the telephone is an important item of security, and to feel safe?

P: Yes.

I: Would you consider also another point in safety such as the time of the day, the specific place, would you consider that some places wouldn't be safe around the school, you would consider distance to be related to safety?

P: Regarding the school right now, what I can say is that, she's starting on Friday. She's starting a new school, so that's a whole different thing I don't know as yet, but for the first week I will be taking her, to see how it is. So regarding those questions, regarding that school I can't answer you right now.

I: You can consider the previous school term to answer the question as we don't know much about the upcoming term yet

P: Yes, around the school and zone it's safe. There's one sort of little alley which would let in front of the school and with houses there, so, like, so she on one day she used to go a bit earlier to her music class, so it was a bit concerning about that. So, it's about two minutes when the bus drops her out to get to the entrance of the school so, first I used to tell her, once you drop off on the bus and she's passing through the alley and she don't have any friends with her you know, like, if there's no other children on the bus with her that time then you just run across. Make sure you call me when you get there, make sure you call me when you get to the school yard. So, that was kind, she would, once she get to the school yard, she would call me and say "Ok mama I'm in school now" and then I'm at least – Ok she's at school now, so it's alright.

I: Ok. So, you said something about being too early, and what time would you say that would be too early?

P: That used to be, he had to reach school at 8 o'clock in school, so, we're looking at about ten to eight something like that because we would walk all together and she would get her bus to school and I would get my bus to go to work so we, but, again we would be in contact over the phone, so ok I got my bus now you know that sort of thing.

I: Does your daughter's school offer a suitable place to keep the bike?

P: Yes, they had a place for bicycles, yes.

Appendix XVIII: Framework matrix with themes

ID	RESOURCES	SAFETY	ENVIRONMENT	SOCIAL	INFRASTRUCTURE	PERCEIVED BENEFITS OF CYCLING
1						
2						
3						
4						
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18						

Appendix XIV: Example of the completed framework matrix with themes

ID	RESOURCES	SAFETY	ENVIRONMENT	SOCIAL	INFRASTRUCTURE	PERCEIVED BENEFITS OF CYCLING
1	So she didn't go riding, which she was very upset about but, I couldn't help it. I'm not just going to buy a bike just for that. Yeah, so, she has a bike, she loves riding, but her bike now is too small for her now. So she has no way, she needs to get a new bike. But,	She goes to school and she come back and no one harasses her or anything like that. Then I can say 'yes, that is fine'. But, like now I can't say, do you understand what I'm coming from. So, in that aspect, we can only say, 'ok, it's going to work out'.	Distance would be the main [reason] because the weather comes after. But the distance… she wouldn't be able to walk, especially, and I wouldn't allow her to walk that distance alone. // I would not allow her to ride when it's dark. So like, winter is coming, obviously I'm not… I wouldn't, allow her to take part in that one, you know. The thing is, because it's dark I want her to get home as soon as possible, so I wouldn't allow her to ride the bike. So, with the winter coming, no, that would be out of…, I would not allow it. She would have to dress	I don't want to use the word jealous, but kind of, you know, a child would like to have one [bike] but she/he doesn't have one, so they would pick on that child who has it and that sort of thing. You try, so for me, you would try to avoid those things so, I prefer to keep a low profile, if you understand. To avoid problems. /// She had other friends around, who used to live around here. They used to be riding, so, she used to ride with them. /// If she has a few friends, let's say, riding together to school back and forth then that's fine because you have	The problem is parking the bike. So, when she used to ride, she used to go swimming and she used to go to the leisure centre with it… When she used to go swimming, and then she locked it… and everything for the bike. // It depends because there's a pavement, but then that's the next problem because people walk on the pavement then if it's a busy area then it's hard for you to ride [the bike] on the pavement, so that's a problem also.	I think it [bicycling] goes the same way with the walking, with the same was as riding. Because I know, it's a wise in a sense of they doing that [bicycling] help them, keep them health, doing that exercise… So not necessarily they get that going to the gym or doing exercise. Walking, or riding the bike helps them with that, you know. Again, like when they get to school pleased and sort of look… So I don't know if that sort of basis, what you're looking at, helping wise for riding the bike

	because, well, we cannot afford to buy one now anyhow so she has to deal with that.		properly and that sort of thing	other people with you, you have other friends with you. I think that make parents feel safe or the carer or whoever, makes the child feel safe also. Because they are not by themselves you know, they have, even if its one person with them, you know that helps.		
2	I can take him by car, you know, it's not a big hustle for me to take him by car but if there is something I need to do, he totally understand s that and he cycle.	Yeah, I mean for me, again…if it's raining…it's just a little slippery, it could cause a huge accident, you know, and he could be in hurt. I'd rather not put him through that. So if it is [bad] weather at all, I would not really… He is actually off	You know, if… during the summer months I'd say it's good weather, I want him to ride anyway. Just because it's good weather and to make use out of traffic. The traffic I get stuck in to take him there. You know I don't need to [be] stuck in traffic when he can actually cycle in 15 minutes to be there. So, yes, definitely, but if it's dripping down rain, I won't make him cycle, I do say to him,	We don't really depend on anyone else, generally, to pick him up, from school. Trying, from time to time, yes, maybe one person, a friend might pick him up. But, otherwise, generally it's me that makes that decision and he would have to go with the flow.	He does go along the pavement. He does cycle on the pavement, because the road, yeah, is the main road that he would have to go down and then the traffic down there and the cars are just [sigh] not kind. So, I actually encourage him to use the path, yeah.	The advantage is big time… is keeping active and yeah, time keeping. He is better at his own time keeping when he is going by bike. He is much more aware of you know, "oh I need to leave at this time and need to get back at that time".

		the road. I wouldn't really want [him] to cycle while [it] is really tipping down or snowy or anything like that, I wouldn't want him to… just that slight little bump up the curve could slip the tire, yeah, and then I'm not there to help him, so I wouldn't want him to be in that situation.	perhaps one or two times per week, I would like you to cycle.			