Development and implementation of a school-based exercise intervention programme designed to improve physical well-being and physical function in children with overweight and obesity.

A thesis submitted by:

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Literature Publications.

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Presentations

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Le Warne, M., Mahaffey, R. **.** (2018) Development of a best evidence foot and lower limb intervention programme for overweight and obese children. *Foot and Ankle Biomechanics.* New York, USA.

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Abstract

Childhood obesity is a rising health concern in the UK associated with reduced physical function and physical well-being. Exercise interventions targeting paediatric obese populations report low attendance and adherence and often neglect the experience and needs of children. The purpose of this thesis is to review previous intervention research in consideration of reported associations between childhood obesity, physical function, and physical well-being, combined with exercise theory for strength and postural stability development, to design an intervention for delivery in primary schools. The aims of this thesis were to first assess the reliability and change statistics of key physical function measures, including isokinetic dynamometry, clinical physical function, and 3D gait assessment, in children with overweight and obesity (OWB). Secondly, to design, pilot, and refine a feasible, school-based exercise intervention aimed at improving postural stability and muscular strength in children with OWB while also addressing the psychological needs of children with OWB. Finally, to evaluate the effectiveness of this intervention (Co-produced with children with OWB targeting Postural stability and muscular Strength: COPS intervention) and to determine the impact on physical well-being and physical function. The reliability study assessed laboratory and clinical assessment of children's (*n*=22) physical function using a 1-week test-retest design, focusing on minimally detectable change (MDC) statistics. A pilot of an eight-week intervention with 14 children with OWB (intervention group *n* = 7, control group *n* = 7) was conducted to examine intervention feasibility and effectiveness, with emphasis on children's reported enjoyment and need satisfaction. Following the pilot phase, a co-production approach, collaborating directly with children (n = 12), addressed identified challenges from the pilot. The eight-week COPS intervention was then delivered in five schools (intervention group n = 22, control group n = 17). Children with OWB exhibited greater reliability and lower MDC statistics compared to typical weight (TW) peers. Additionally, children with OWB demonstrate greater variability in gait, likely due to the challenges of controlling and moving their larger mass. The pilot study revealed that children's motivation may play a critical role in intervention effectiveness as this results in low attendance and adherence, limiting any beneficial result to physical function and physical well-being measures. Interventions for children should meet the needs of children for motivation and enjoyment, and this may be even more important for children with OWB, who generally engage in less activity. A co-production approach allowed for intervention refinement by altering the delivery format, exercise variation and means to track engagement, aligning with children's preferences and needs. The concluding COPS intervention demonstrated sustained engagement and higher activity intensity levels than typical physical education classes. Pre-intervention, post-intervention, and follow-up laboratory and clinical physical function assessments showed the COPS intervention to have improved performance in lower limb muscle strength, as well as performance in clinical physical function tests. The research highlights the promising effects of a co-production approach to intervention development in school-based exercise interventions and the potential benefits of strength and postural stability focused exercise to children with OWB's physical function. This work provides support for child-centred and evidenced-based active play that may help inform teaching styles (i.e. autonomous supportive environments), PE curriculum design (i.e. prioritising play and activity with the broader aim of physical function over sports skills) and future research (i.e. further intervention adaptation, examination of the role of motor co-ordination and relationships of physical function and physical well-being in children with OWB).

Word count:76,337.

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List of Abbreviations

Abbreviation	Definition
1RM	One Repetition Maximum
3D	Three dimensional
4C	Four compartment
6MTW	Six Minute Timed Walk
ADP	Air displacement plethysmography
AUC	Area under the curve
BIA	Bioelectrical Impedance Analysis
BMC	Bone Mineral Content
BMI	Body Mass Index
BPN	Basic Psychological Needs
CET	Cognitive evaluation theory
CHQ	The Child Health Questionnaire
CI	Confidence Interval
CV	Coefficient of variation
CVD	Cardiovascular disease
DCGM	Disabakids chronic generic measure
DEXA	Dual Energy X-ray Absorptiometry
FFM%	Fat-Free Mass %
FFMkg	Fat-Free Mass kg
FM%	Fat Mass %
FMkg	Fat Mass kg
FMS	Fundamental Movement Skills
GRF	Ground Reaction Force
HHD	Handheld Dynamometer
HRQoL	Health-Related Quality of Life
ICC	Intraclass Correlation Coefficient
ICF	International Classification of Functioning
MDC	Minimal Detectable Change
MSK	Musculoskeletal
MVPA	Moderate to Vigorous Physical Activity
NHS	National Health Service
OA	Osteoarthritis
OR	Odds Ratio
OW	Overweight
OWB	Overweight and Obesity
PA	Physical Activity
PAC-Q	Physical Activity for Older Children Questionnaire
PE	Physical Education
PEDSQL	Paediatric Quality of Life Inventory
PPQ	Paediatric Pain Questionnaire
ROC	Receiver operating characteristic
RR	Relative Risk
SDT	Self Determination Theory

SEM	Standard Error of Measurement
SLS	Single Leg Stance
SPM	Statistical parametric mapping
STS	Sit to Stand
TBW	Total Body Water
TGV	Total Gas Volume
TUG	Timed Up and Go
TW	Typical Weight
UK	United Kingdom
USA	United States of America
UW	Underweight
VAS	Visual Analogue Scale

Thesis Introduction

Approximately one-third of children in the United Kingdom (UK) are classified as having overweight and obesity (OWB), and these children are more likely to remain having OWB into adolescence and adulthood, increasing the risk of obesity comorbidities such as cardiovascular disease, insulin resistance, cancer and musculoskeletal (MSK) pain. Additionally, OWB in childhood is associated with reduced physical well-being (pain, physical health-related quality of life [HRQoL] and physical activity [PA] behaviour) and physical function (strength, postural stability, performance in tasks of daily living). Chapter 1 of this thesis reviews the current literature, outlining current findings of reduced physical well-being (increased pain, lower physical HRQoL and PA) in children with OWB, which demonstrates the wide impact OWB and physical function deficits in children may have. Additionally, Chapter 1 evidences deficits of lower limb strength and postural stability in children with OWB, which underpin physical function deficits in children with OWB and impacts daily tasks of living such as walking. Furthermore, the impact of OWB on gait is reviewed as a detailed biomechanical examination of a key functional movement to provide a thorough examination of potential MSK risks for pain and function deficits. Lower limb muscular strength and postural stability are presented as key targets to address the negative cycle of lower physical function and associated physical well-being in children with OWB. Lastly, this chapter reviews current knowledge of exercise interventions to improve muscular strength and postural control in children with OWB to understand the potential effects on body composition, physical function and physical well-being.

The aims of the thesis were to develop an intervention and explore how strength and postural stability may be improved in children with OWB through a school-based exercise intervention and to understand what effect, if any, this has on body composition, physical function (including changes in gait), and physical well-being. The initial conclusions from reviewing intervention literature led to the piloting of a school-based exercise intervention (Chapter 4). The pilot intervention was examined for feasibility (including recruitment, attendance and adherence) and effectiveness of the intervention on outcome measures of physical well-being and physical function, which are outlined in the general methods (Chapter 2).

The pilot intervention generated a pivotal question regarding attendance and adherence to exercise interventions in children with OWB. Understanding children's motivation quality was then further explored through the pilot study’s post-intervention focus groups to understand the participants' experience of the exercise intervention. Additionally, it also became apparent from the pilot study that OWB child-specific reliability and change statistics were needed to understand meaningful changes in physical function measures from the intervention. In the following data collection period, thesis progression was paused due to the global Covid-19 pandemic. Upon returning to research activity, a reliability study (Chapter 3) of the measures used to quantify physical function in children with OWB was conducted. Furthermore, Chapter 3 provides key change statistics, specifically for children with OWB. Moreover, to further build upon the qualitative findings of the pilot study (Chapter 4), a co-production process was conducted to develop the intervention.

The co-production process outlined in Chapter 5 was based on the findings in the pilot study and structured on the self-determination theory framework to develop the pilot exercise intervention. The co-production approach involved working with children to provide detailed insight so the intervention may better meet their needs and provide a positive exercise experience while also remaining focused on increasing lower limb muscular strength and postural stability. The developed intervention aimed to provide more novelty and autonomy and allow participants to feel appropriately challenged. The findings from the co-production process significantly altered the intervention delivery format and style, exercise selection and methods for tracking engagement.

Chapter 6 implemented the newly developed *C*o-produced with children with OWB targeting *P*osture stability and muscular *S*trength (COPS) intervention and its effects on physical well-being and physical function. The effectiveness of the COPS intervention for adherence and sustaining engagement was examined, and the impact on physical function and physical well-being post-intervention and follow-up was examined. Findings in physical function were also assessed relative to minimal detectable change statistics derived from the reliability study (Chapter 3).

Chapters 7 and 8 of the thesis discuss the findings from each empirical study relative to the thesis aims set out in Chapter 1 and examines the importance in the context of previous literature and impact on children with OWB's physical function and physical well-being. The limitations of the thesis are discussed together with ways in which they were mitigated, contextual lessons learnt and focus for future research to address them. Finally, the novel aspects of the thesis (e.g. intervention design methods and combination of physical function and physical well-being outcome measures) are presented in conjunction with implications for the current understanding regarding the relationships between physical function, physical well-being and OWB in children, as well as intervention design for children with OWB.

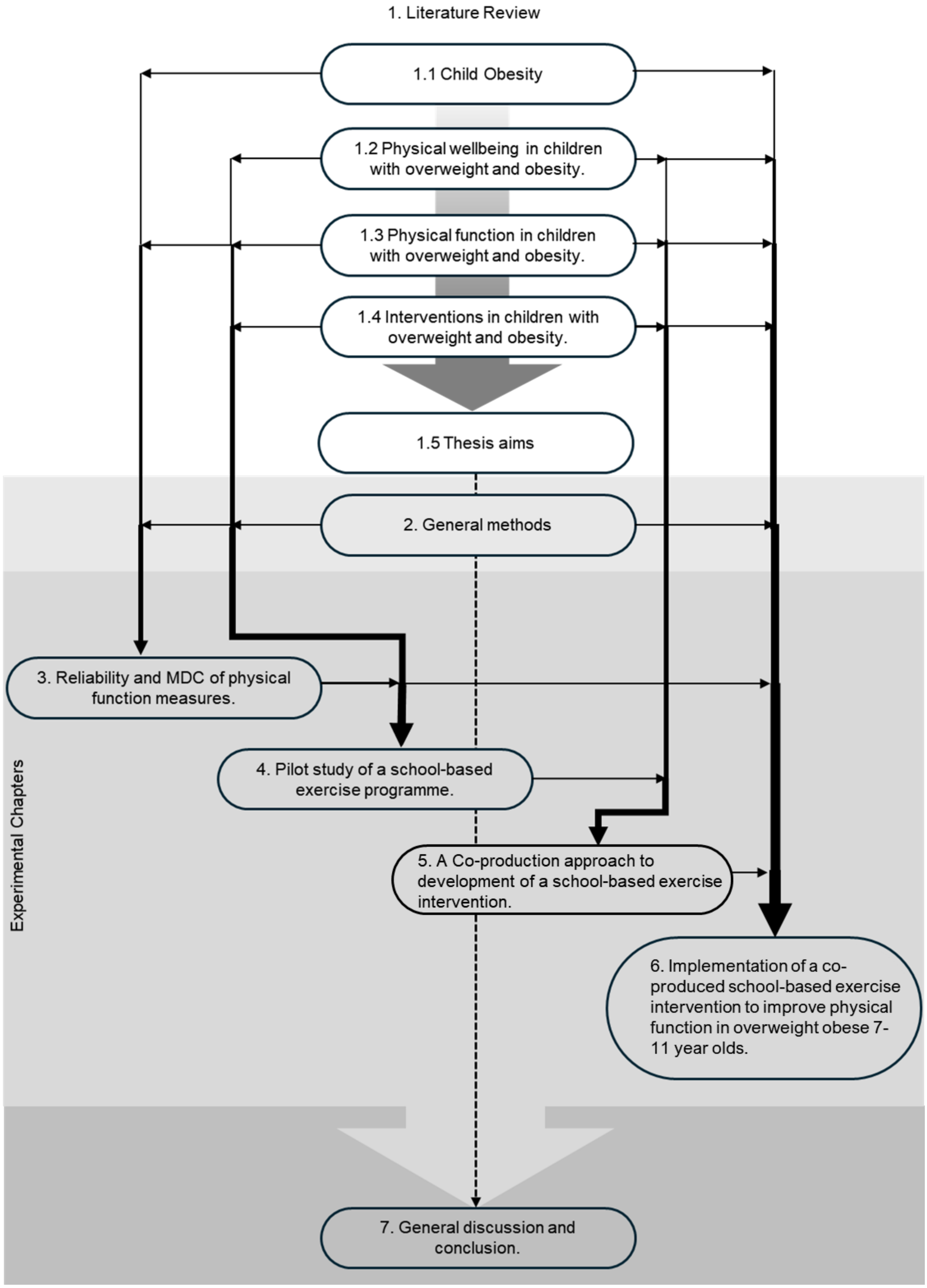

Figure 1. Overview of the thesis structure and contribution of each chapter to the following chapters.

1 Literature review of physical well-being, physical function, and exercise interventions in children with overweight and obesity.

This chapter reviews the literature on childhood overweight and obesity (OWB), its impact on physical well-being, physical function, and related exercise interventions. The focus of this thesis and literature review is based on developed frameworks of disability and physical function (Ross et al., 2016; Tsiros et al., 2020), synthesising findings on the physical impacts of childhood obesity and mapping to the well-established International Classification of Functioning, Disability and Health (ICF; World Health Organization, 2007). Figure 1-1 below demonstrates the organisation of the literature review and rationale for experimental studies relative to the ICF framework (Figure 1-2). The first section (1.1) addresses the escalating issue of childhood OWB, the complicated nature of assessing and measuring OWB in children, and its health implications. The second section (1.2) examines the effects of childhood OWB on participation and activities summarised as physical well-being, with a focus on musculoskeletal (MSK) pain, health-related quality of life (HRQoL) and physical activity (PA). The third section (1.3) examines how childhood OWB affects body function and structures through limiting physical function with a detailed review of measurements of physical function, muscle strength, and gait. Section 1.3 identifies postural stability and lower limb strength as personal factors for intervention in childhood OWB. The fourth section (1.4) evaluates exercise interventions to enhance physical function in children with OWB and discusses psychological factors that influence intervention effectiveness. The aims, key concepts, and novelty of the research are summarised in section 1.5, underscoring the necessity of the research presented in the experimental studies (Chapters 3, 4, 5, and 6).

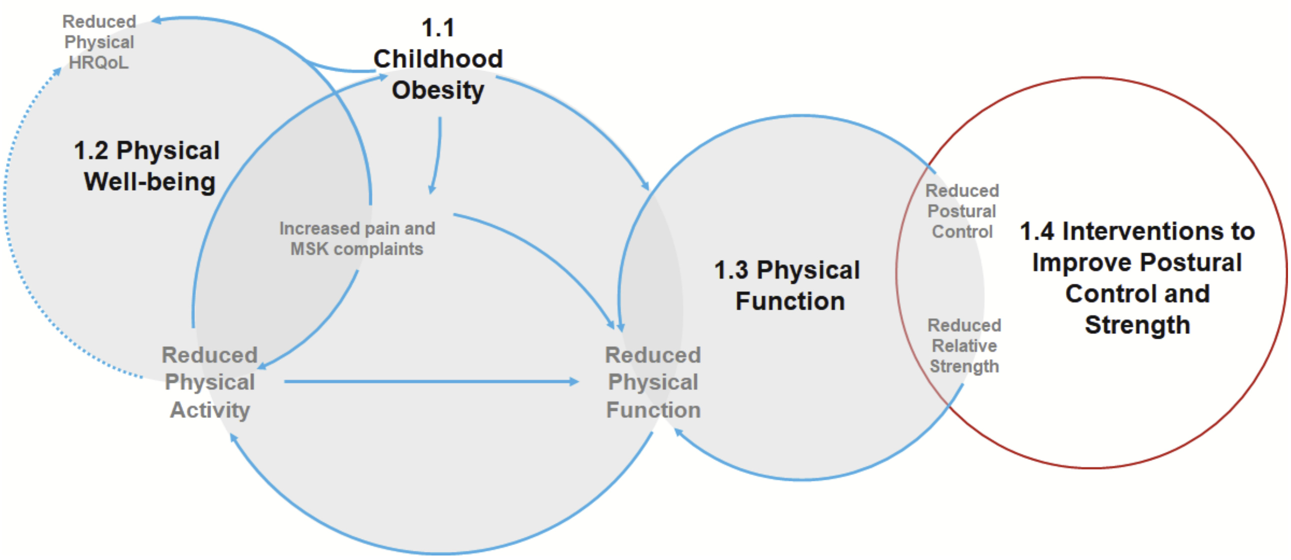

Figure 1-1 Schematic of interconnected factors in childhood obesity relative to sections of the literature review.

Note: Numbers refer to chapter sections

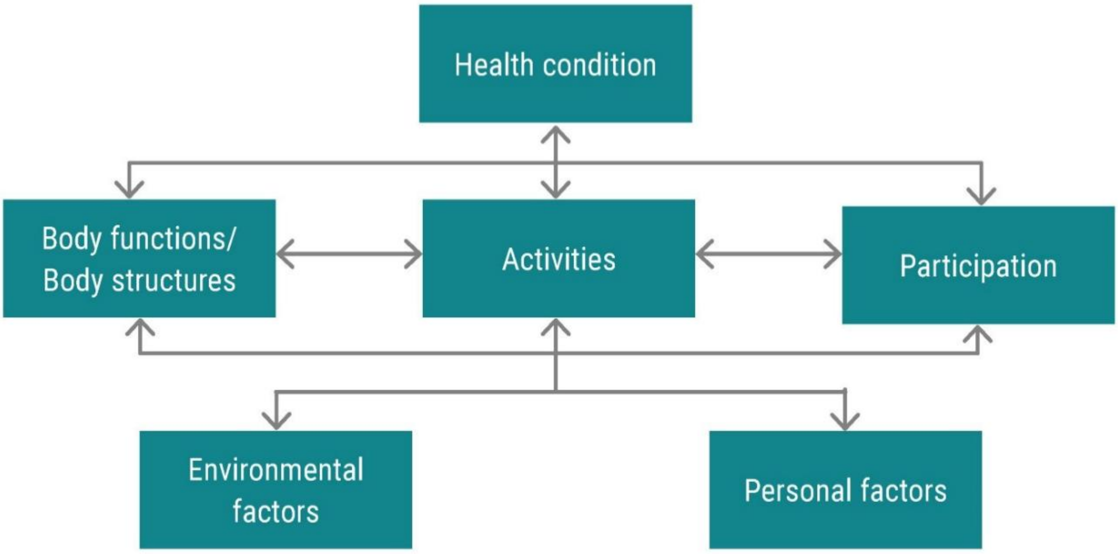

Figure 1-2 Diagram of the International Classification of Functioning, Disability and Health (WHO, 2007).

1.1. Child overweight and obesity.

This section details the definition and prevalence of OWB in children in the UK and explores its complex aetiology. It also discusses methods to measure body fat in children, including considerations in estimation equations, and compares air displacement plethysmography and bioelectrical impedance as two available methods in the current thesis. Finally, this section reviews the impact OWB has on children's health.

1.1.1 Prevalence of overweight and obesity in children.

In 2016, it was estimated that 340 million children and adolescents worldwide had OWB (World Health Organization, 2019). The prevalence of comorbidities associated with OWB, such as type 2 diabetes and hypertension, has increased in children and will continue to rise with childhood OWB rates (Lobstein & Jackson-Leach, 2016). There has been a worldwide trend for increasing levels of OWB in children year-on-year, with some records tracking increasing rates from as early as 1975 (Bentham et al., 2017; Di Cesare et al., 2019). High-income countries (i.e. UK, USA and Australia) report levelling (slowing or no further increases) rates of OWB in children (but prevalence remains high), whilst median to low-income countries are starting to develop rapidly increasing levels of OWB each year (Bentham et al., 2017). The National Child Measurement Program measures the height and mass of 5-6-year-old and 10-11-year-old children in the UK. Data from 2023/24 show that 22.1% of 5-6-year-olds and 35.8% of 10-11-year-olds have OWB, and therefore when leaving primary school, over a third of children in the UK are at risk of associated comorbidities and impacts to their physical well-being and physical function (Sections 1.2 and 1.3 reviews these topics further).

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1.1.2 Definition and measurement of overweight and obesity in children.

The definition of OWB is an excess of fat mass (FM) to the extent that health is adversely affected (Kopelman et al., 2009). Whilst adult OWB is defined on thresholds for anthropometric (e.g. body mass index [BMI]) and FM% measures derived from mortality and comorbidity data, such data are sparse for children. Therefore, defining obesity in children based on health consequences is challenging (Flegal, 1993). Moreover, children will exhibit different patterns in growth and maturity between ages and genders compared to the relatively stable anthropometrics in adulthood. Therefore, fixed BMI thresholds are not appropriate for children and alternative methods to classify weight based on growth patterns are needed (Scientific Advisory Committee & Royal College of Paediatrics & Child Health, 2012).

1.1.3 Weight status classification in children.

Classification of child weight status is most commonly determined by comparing BMI (body mass / height ^{2}) to a national or international reference population of children relative to age and gender, given as a distribution score (*z*-score or percentile). BMI Z-score and percentile thresholds or cut-offs for age and gender are used to determine weight status (Table 1-1). Several national and international reference populations and corresponding cut-offs exist for defining OWB in children. The UK growth reference data 1990 (UK90; Cole et al., 1995) includes height and weight measures of 37,000 youths (0 to 22 years). Current thresholds based on this reference population are shown in Table 1-1. Both population thresholds (overweight 85th and obese 95th centile) and clinical thresholds (overweight 91st and obese 98th centile) exist for UK90 reference data (Cole et al., 1995). Groups of participants in non-medical studies may be defined as OWB (including all children over the 85th and 95th centiles), overweight (including only children between 85th and 95th), or obese (including only children over the 95th centile) and will be described using these terms throughout the thesis. However, it should be noted that alternative reference populations (from different countries) and cut-off thresholds can cause a disparity in reported prevalence and difficulty in comparing studies (Scientific Advisory Committee & Royal College of Paediatrics & Child Health, 2012).

Table 1-1 UK90 centile and Z-score thresholds and corresponding Department of Health population tracking weight status classification*.

Centile	Z-score	Weight Status
0.2nd – 5th	-3.00 to -1.64	Underweight
15th – 84th	-1.04 to 1.00	Healthy weight
85th – 94th	1.00 to 1.64	Overweight
95th – 99.8th	1.64 to 3.00	Obese

*Values from Wang and Chen (2012)

BMI is often used to define OWB in large-scale and population-based studies due to its simplicity and association with cardiovascular risk factors (Javed et al., 2015; Reilly et al., 2010). However, BMI is not a measure of excess FM (or adiposity) and is based upon assumptions of body composition as it cannot distinguish between levels of fat-free mass (FFM) and FM. BMI has high specificity (ability to identify those who do not have high excess FM correctly) but lower sensitivity (ability to identify those with excess FM positively; Javed et al., 2015). Therefore, using BMI as a surrogate measure for adiposity in children and adolescents may not capture all children with excess FM (Javed et al., 2015). Additionally, the use of BMI compared to FM% may not successfully identify all children and adolescents with increased cardiometabolic risk factors as a result of excess FM (Zapata et al., 2023).

1.1.4 Measurement and identification of excess body fat in children.

Body composition assessment is the quantification of body tissue into compartments, and methods are typically organised by the number of compartments quantified (Ellis, 2000), shown in Figure 1-3. Two-compartment models indirectly estimate FM and FFM. Two-compartment models are based upon the assumption that the density of FM (0.9kg/L) and FFM (1.1-0.9 kg/L) remains constant (Fields et al., 2002). FM density is relatively stable, but FFM may vary greatly between individuals (especially between age groups) due to changes in hydration, mineral, and protein content (Fields et al., 2002). The three-compartment model quantifies FFM into lean tissue and total body water (TBW), and the four-compartment model separates FFM into water, bone mass, and protein (Ellis, 2000). Three-compartment models improve estimates of FM in healthy adults and older children, and four-compartment model methods are theoretically more accurate in estimating body composition still but require multiple measurements and are not feasible in all settings (Ellis, 2000).

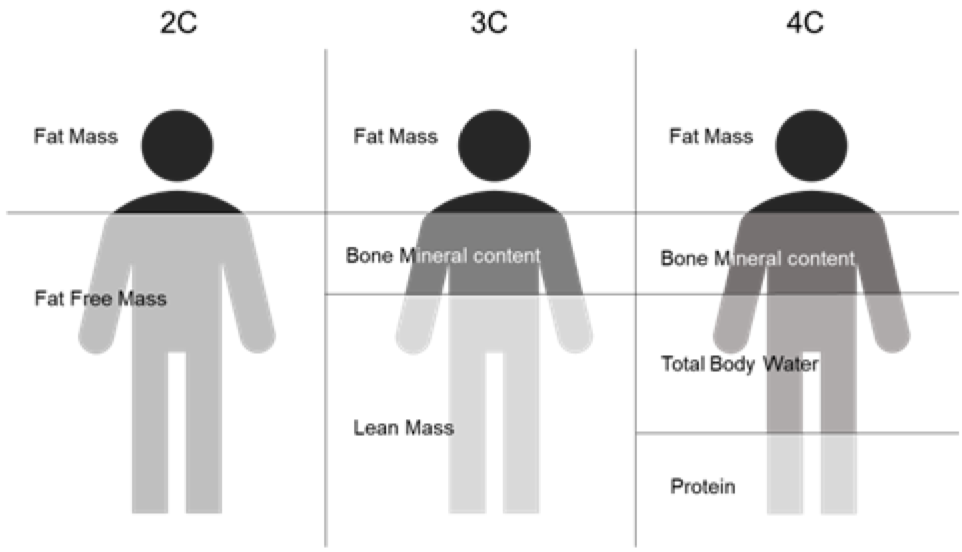

Figure 1-3 Summary components of body composition models.

Methods to measure FM include density measurements (underwater weighing, air displacement plethysmography [ADP]), bioelectrical impedance (BIA), scanning methods (e.g. dual-energy x-ray absorptiometry [DEXA]), TBW dilution, and anthropometric measurements (e.g. skinfolds: Sweeting, 2007). Methods such as underwater weighing may be less appropriate for paediatric populations as they require complete submersion in water. Other methods, such as DEXA, require specialised expensive equipment and expose individuals to a small dose of radiation, which may be less appropriate for children, particularly in studies requiring multiple measurements (Sweeting, 2007). ADP and BIA present safe and acceptable protocols for use in children that are sensitive to determining changes in FM% (Atherton et al., 2013; Frisard et al., 2005). Sections 1.1.4.1 and 1.1.4.2 review the use of ADP and BIA for measurement in Children with OWB and compare these 2C models to criterion 3C or 4C models (DEXA scan or combination DEXA and density methods).

1.1.4.1 Air displacement plethysmography.

ADP measures total body volume, allowing for the estimation of FM and FFM adjusted for age and gender. The BodPod (COSMED, Life Measurements, Inc, Concord, CA) device consists of a reference chamber and a test chamber. Body volume is calculated by comparing the volume of the empty test chamber to its volume when the participant is inside. The device uses the pressure-volume relationship (Poisson's Law) to estimate the test chamber's volume, considering the isothermal nature of air in the lungs, around the skin, in hair, and in clothes (Fields et al., 2002). ADP is considered to be a highly valid and reliable estimator of body composition (von Hurst et al., 2016). However, several factors affect the validity of ADP body composition estimates in children.

1.1.4.1.1 Population specific equations for estimating body composition *using ADP.*

The standard thoracic gas volume (TGV) estimation (i.e. air in the lungs which must be adjusted for body volume calculation) in the BodPod software is based on adult studies, making it inappropriate for children. Fields et al. (2004) provided a child-specific TGV estimation equation based on 224 children aged 6 to 17 years. Additionally, the Siri equation (Siri, 1961) for body density used in BodPod software, estimations of FM and FFM are invalid for children due to changes in water and mineral content in FFM during growth. Using age- and gender-specific body volume equations (ADP_{Lohman}) from Lohman (1989) is more appropriate for children. Haycock et al. (1978) provided estimates for surface area artefacts that are more applicable to paediatric body composition assessment, considering a diverse range of body types, ethnicities, and ages.

1.1.4.1.2 Validity of ADP compared to criterion methods in paediatric populations.

ADP and 4-compartment model estimation of FFMkg and FM% in OWB youth are highly correlated (r = 0.819 – 0.95, p <0.05; Gately et al., 2003; Vásquez, 2016). Comparisons between ADP_{Lohman} and 4C models in OWB youth demonstrate no significant difference in the estimation of FM% (-0.4 ± 3.6 %) or FMkg (-3.17, 95%CI [-7.92, 1.58] kg; Gately et al., 2003; Vásquez, 2016). Although, ADP_{Lohman} significantly underestimates FM% (-3.80 ± 3.30) in severely obese children (defined as > 97th percentile for age and sex) compared to DEXA scans (Lazzer et al., 2008; Orsso et al., 2020). However, it should be noted that DEXA may overestimate FM relative to the 4C models because of variations in estimations of TBW and FFM from the different methods (Gately et al., 2003). ADP, therefore, appears to be valid children with OWB relative to gold standard 4-compartment models.

1.1.4.1.3 Reliability of ADP in paediatric populations

Reliability in ADP measurements is influenced by the ability to control for factors affecting volume calculations. The BodPod mitigates the effect of isothermal air by requiring subjects to wear minimal clothing, such as Lycra, and a swimming cap to compress hair (Dempster & Aitkens, 1995). The BodPod software also estimates skin area artefacts using body weight and height to calculate body surface area, based on Dubois and Dubois (1916) estimates for body surface area. Additionally, measuring TGV in children poses reliability challenges. The TGV protocol requires participants to breathe through a plastic tube and gently puff against an occluded valve mid-exhalation, which children often struggle to perform reliably (Lockner et al., 2000). The child-specific TGV estimation equation provided by Fields et al. (2004) enhances reliability in paediatric populations. Gately et al. (2003) reported a coefficient of variation of 4.0% in 44 children and adolescents with OWB performing same-day measures of FM% using ADP_{Lohman}.

1.1.4.1.4 The ability of ADP to detect change in body composition.

The ability of ADP to detect changes in body composition is crucial for tracking the progress of interventions in children with OWB. DEXA-measured changes in FM% are highly correlated with corresponding ADP_{Lohman} estimates (p < 0.001, R^2 = 0.57, standard error of measurement [SEM] = 0.08). Nevertheless, ADP using the Lohman equation somewhat overestimates changes in FM% in Children with OWB by 1.20 ± 5.32% (p <0.05) compared to DEXA (Elberg et al., 2004). Overestimation of FM% changes suggests that while ADP can detect changes in body composition, careful consideration of the population-specific equations and models used is essential. The BodPod is expensive and not available in many settings, and sitting within an enclosed chamber may not be comfortable for all children, particularly younger children (Bijlsma et al., 2023). Therefore, it is important to examine alternative methods to assess body composition in children.

1.1.4.2 Bioelectrical impedance.

BIA is a cost-effective tool used in research and clinical settings with low participant burden (Brantlov et al., 2017). BIA uses the principles of electrical conductivity to estimate body water. A weak alternating electrical current travels through the body from sensor to sensor (typically either foot-to-foot or foot-to-hand for whole-body estimates), and the opposition to the current (impedance) is calculated (Brantlov et al., 2017). TBW is estimated from electrical current resistance and an assumption of body geometry from height and mass (Brantlov et al., 2017). Tissues that contain less water, such as fat, have low conductivity and, therefore, high impedance (Brantlov et al., 2017). Estimates of body composition from TBW are based upon the assumption that 73% of FFM is water (Lee & Gallagher, 2008). Calculations of composition estimates (i.e. FM, FFM) rely on these assumptions. However, the constants used in these calculations vary for age, gender, and health status (Kyle et al., 2015). Through childhood, FFM hydration decreases as density increases, and Wells et al. (2010) reported significantly lower density values in children (1.0864 kg/L) compared to values (1.1 kg/L) for adults. Therefore, estimates of TBW are susceptible to changes in growth and maturation (Wells et al., 2010).

Brantlov et al. (2017) recommended that the assessment of BIA of children be performed ideally after a 4-hour fast. However, the authors recognise that fasting may not always be feasible and noted that ingestion of fluid prior to assessment does not significantly alter whole-body resistance (Brantlov et al., 2017). PA should be avoided 4 hours prior to BIA measurement. To mitigate factors out of the control of the researcher, BIA measurements should be taken at the same time of day in longitudinal studies to replicate the hydration state and reduce the effect of intake from different meals (Brantlov et al., 2017). Adult recommendations are that participants should lay supine for 5-10 minutes prior to the assessment to allow for sufficient fluid stabilisations, electrodes should be > 4 cm2 in surface area and placed > 5 cm apart to avoid electrical interaction.

Additionally, during measurement, the arms and legs should be abducted ~45 ° with minimal movement to decrease electrical interaction and interferences, which may introduce errors in the estimation of impedance (Brantlov et al., 2017).

1.1.4.2.1 Validity of bioelectrical impedance analysis compared to reference measures.

The validity of BIA is influenced by the equations applied to estimate FM and FFM, which vary significantly across manufacturers and populations. Most BIA units apply their own proprietary equations which are derived from adult reference data, potentially leading to inaccuracies when applied to paediatric populations (Kyle et al., 2015). Evidence suggests that using population-specific equations improves BIA estimates. For example, in 7-year-old children, FM estimation errors reduced from 13% (using manufacturer equations) to 4.62% (child-specific derived equations) when compared to DEXA (Luque et al., 2014). Similarly, comparisons of manufacturer equations to DEXA in children with OWB showed an underestimation of FM% by 8.5–14.6%, varying by gender (González-Ruíz et al., 2018). However, this underestimation decreased to ~ 5.8% when population-specific equations were used (Lazzer et al., 2008). These findings highlight that generalised equations, particularly those developed for TW cohorts, are less applicable to children with OWB due to differences in body geometry and water distribution (Lazzer et al., 2008).

Hydration status also plays a critical role in BIA accuracy. Children with OWB, for instance, demonstrate altered TBW distribution. Battistini et al. (1991) found that BIA significantly underestimated TBW in obese children regardless of the equation applied, with errors ranging from -2.7L (manufacturer equations) to -5.7L (Davies et al., 1988). However, the Davies equation was based on a small sample size of 26 children and adolescents and was not OWB-specific (Davies et al., 1988). A comprehensive review by Orsso et al. (2020) further underscores the limitations of BIA in children with OWB. Across 26 studies comparing BIA to 4C model, BIA generally underestimated FM% (-7.09% to -0.6%) and overestimated FFMkg (+2.3 to +5.9 kg). Notably, many of these studies relied on manufacturer-provided equations, which were not specifically designed for OWB populations. This emphasises the need for tailored equations to improve BIA's validity in OWB paediatric cohorts.

1.1.4.2.2 Reliability of bioelectrical impedance analysis in overweight and obese children

A review of 20 studies assessing the reliability of BIA in children and adolescents, including both OWB and TW cohorts, reported high interclass correlation coefficients (ICCs) for FM%, FMkg, and FFMkg, all ICCs exceeding 0.96. Measurement errors ranged from -0.90 to 1.61% for FM%, ~0.5kg for FM, and ~0.15kg for FFM, indicating overall consistency in BIA measurements. However, the methodologies varied significantly between studies, including differences in testing intervals (ranging from 90 seconds to five weeks), electrode placement, and BIA unit types, which may affect reproducibility (Talma et al., 2013).

A Study on obese adolescents using electrode repositioning between tests to simulate longitudinal conditions similarly found a low coefficient of variation (CV) of 2.2% for FFM (Lazzer et al., 2008). Over a longer period, BIA measurements across three consecutive days in 138 obese adolescents showed excellent reproducibility, with ICCs of 0.99 for FM%, FMkg, and FFMkg (Verney et al., 2016). Data on children with OWB is limited (the study was based on only three children), but BIA in children with OWB yielded a low CV of 0.47% for FFMkg, 0.93% for FMkg, and 0.64% for FM% (Kasvis et al., 2015). BIA appears reliable to measure body composition in OWB youth over time and is considered a reliable tool for tracking body composition changes over time (Chula De Castro et al., 2018; Kasvis et al., 2015; Verney et al., 2016).

1.1.4.2.3 The ability of BIA to detect change in body composition.

In children with OWB taking part in a PA programme BIA only detected a significant decrease in FM% (baseline 31.1 ± 4.9%, post 3 months 28.5 ± 6.6) but not increases in FFMkg (baseline 50.0 ± 10.5 kg, post 3 months 50.3 ± 10.5 kg;(Lyra et al., 2015). However, the use of DEXA in the same study showed significant changes in both FM% (baseline 39.6 ± 4.4%, post 3 months 38.5 ± 4.8%) and FFMkg (baseline 42.5 ± 8.9 kg, post 3 months 43.2 ± 8.9 kg; Lyra et al., 2015). Kasvis et al. (2015) found overall agreement in the direction of change for FM%, FMkg and FFMkg between BIA and DEXA during a 6-month lifestyle intervention for children with OWB. These studies demonstrate that BIA is useful for determining the direction of change in children. Measures of change in FFM are likely impacted by the assumed hydration in manufacturer equations used in studies. Phillips et al. (2003) demonstrated BIA to be accurate in estimating the change of FFMkg and FM% over time in adolescent girls as a result of growth and maturation relative to isotope measures of TBW. Phillips et al. (2003) used BIA 101 bioelectrical impedance analyser (RJL Systems, Clinton Township, MI, USA) and several different prediction equations and found that the accuracy of estimates is dependent on the equations used to determine body composition from BIA, and equations should be relevant for the study population (e.g. age or menarche status). Population and unit-specific equations are important for accurate measurement of changes in estimates of body composition in children.

1.1.4.2.4 Population and BIA device-specific equations.

Cleary et al. (2008) compared four child-specific equations to estimate FM% from the Bodystat1500 BIA unit in 33 children with OWB (5-9 years) and cross-validated these estimates with DEXA scan estimates; all equations had an ICC > 0.83. The equation from Houtkooper et al. (1996) best estimated FM% in children with OWB compared to DEXA ($R^2 = 0.86$, $p < 0.001$) with a mean underestimation of 2.62 FM% and underestimation of FFMkg with DEXA ($R^2 = 0.97$, $p < 0.001$) of 1.17kg. Clasey et al. (2011) compared FFMkg estimated from the Bodystat 1500 bioelectrical impedance analyser (Bodystat Ltd., Douglas, Isle of Man) to a DEXA scan in 436 children (5-11 years), including 105 children with OWB, to generate a new prediction equation (equation 2-1). Cross-validation with DEXA, FFMkg showed that the new equation significantly predicted FFMkg (R^2 = 0.952).

1.1.4.3 Comparisons of ADP and BIA

Both ADP and BIA are valid, reliable and safe methods to estimate body composition in children with OWB. Compared to DEXA and ADP, BIA may overestimate FFMkg and underestimate FM% in children. However, this discrepancy is reduced with population-specific equations to estimate body components (Lazzer et al., 2008; Seo et al., 2018). In a group of mixed-weight children, Foucart et al. (2017) found no significant difference between ADP and BIA prediction of FM%. However, BIA did underestimate FM% relative to ADP estimates in children with greater adiposity (Foucart et al., 2017). Similarly, Mahaffey et al. (2023) found a positive strong correlation ($r = 0.80$) between BIA and ADP but FM% was underestimated in BIA (–3.4 ± 5.6 %; effect size = 0.42). BIA may not be used interchangeably with ADP to estimate body composition in children with OWB, and body composition from different methods should not be directly compared. However, BIA is a reliable tool, particularly when measurement guidelines are adhered to unit and population-specific equations are used to estimate body composition and change over time in children with OWB.

1.1.4.4 Summary of measurement and identification of excess body fat children.

The growth and development of children create challenges in the assessment of body composition. Body composition can be measured using ADP and BIA, both of which are suitable for children. Specific estimation equations tailored to paediatric populations help address issues of changing hydration status with growth and should be used when estimating FM or FFM from ADP or BIA. However, both methods are valid and reliable to measure FM% and changes in FM% over time. Identification of OWB in children from FM% is not currently widely applied despite some reference population data (Costa-Urrutia et al., 2019). Identification of FM% thresholds in adults is typically determined by adverse health outcomes and associated biomarkers (e.g. cholesterol), but due to the nature of these comorbidities (in that they take a period of time for adverse body composition and lifestyle factors to arise), data are not widely available or applied in children. Therefore, weight status classification based on BMI-Z-scores is most widely used in investigating causes and outcomes of OWB in children. Whilst BMI Z-Score provides a definition of childhood obesity to define the study population, body composition techniques (particularly ADP and BIA) may provide more sensitivity to changes in OWB status, and therefore, both measures should be considered in research.

1.1.5 Aetiology of overweight and obesity in children.

The causes of OWB are complicated and include genetic, socioeconomic and environmental factors (Omer, 2020). Genetic alterations or mutations may increase a predisposition to obesity, and some may cause diseases or syndromes such as Prader-Willi syndrome, which may affect adiposity in children (Murphy, 2022). Socioeconomically disadvantaged children show an increased risk of obesity-related health problems, namely metabolic syndrome risk factors (measured through blood pressure and cholesterol levels; Iguacel et al., 2018). The causal link between low socioeconomic status and obesity is theorised to stem from unhealthy behaviours, such as consuming energy-dense but affordable food and engaging in sedentary activities, as well as poor mental well-being due to increased chronic stress (Iguacel et al., 2018; Weihrauch-Blüher & Wiegand, 2018). Environmental factors include the cultural environments of home and school, which influence key health behaviours like PA, sedentary behaviour, and diet, as well as neighbourhood such as access to safe outdoor spaces, active transportation, and food availability (Procter, 2007). Each of these factors may interact in a complex way to cause OWB in children (Maffeis, 2000). However, with the exception of diseases or syndromes resulting from genetic alterations, the fundamental issue of simplified obesity is a result of energy imbalance that leads to excess weight gain. When energy intake from food exceeds energy expenditure through PA, metabolic processes, and growth, the surplus energy is stored as FM (Goran & Treuth, 2001). Both excess energy intake and insufficient PA contribute to a net positive energy balance, which may lead to obesity and detrimental health effects in children.

1.1.6 Effects of overweight and obesity on children

As discussed earlier (Section 1.1.1.), childhood OWB is a significant and growing problem in the UK. The estimated cost of obesity to the National Health Service (NHS) is substantial, with annual costs reaching approximately £6.5 billion (Scarborough et al., 2011). Children with OW are more likely to be OWB during adolescence, and 80% of obese adolescents will still be obese in adulthood (however, not all adults with OWB were children or adolescents with OWB; Simmonds et al., 2016). The effects of OWB on children are widespread, impacting mental well-being, physical health, and physical well-being. Addressing childhood OWB is thus crucial for mitigating these extensive effects and reducing future healthcare costs as children with OWB become adults with OWB, perpetuating a cycle of health issues that extends into later life.

1.1.6.1 Psychological effects of overweight and obesity in children

The psychological health of children and adolescents with OWB is deeply affected by societal and peer perceptions (Creese et al., 2023; Fields et al., 2021). Children and adolescents with OWB experience more bullying due to their weight and report significantly (β-0.16 (-0.22 to -0.11)) lower self-esteem (Fields et al., 2021). Higher BMI *Z*-scores at age 11 years are associated with lower self-esteem and reduced happiness with appearance in adolescence (Creese et al., 2023). These findings demonstrate the effects of weight bias on children with OWB's social experience and the lasting impact on mental health as children mature.

1.1.6.2 Physiological effects of childhood overweight and obesity on health

In a review of 89 studies, Guh et al. (2009) demonstrated a link between higher BMI in adults and the incidence of comorbidities such as diabetes, cancer, cardiovascular disease (CVD), asthma, gallbladder disease, osteoarthritis and chronic back pain. Many of these diseases may take some time to occur and, therefore, are not typical in children with OWB, but precursors to these comorbidities are present. For example, in Canadian 6-to-19-year-olds (n = 2086), Maximova et al. (2013) established that CVD risk factors, such as adverse blood pressure and cholesterol levels were predicted by higher BMI, and that controlling for confounding factors (i.e. gender, age, socioeconomic status, and health behaviours such as daily steps, soft drink consumption and sleep) did not alter the relationship. In a UK study of 103 obese 2-to-18-year-olds, one-third were identified as having insulin resistance syndrome (which may be a precursor to type 2 diabetes; Viner, 2005). Whilst none of the 103 participants were identified as having type 2 diabetes, and it does remain rare for children to do so, it is not unprecedented and appears to be an emerging problem (Song & Frier, 2022). However, what appears to be more prominent in children with OWB is musculoskeletal (MSK) complaints (Chan & Chen, 2009).

1.1.6.3 Impact of overweight and obesity on musculoskeletal health of children.

Healthy MSK development is essential for physical well-being and physical function, and it can be severely impacted by factors such as hormonal deficiencies, autoimmune diseases, genetic conditions, and obesity (Levangie & Norkin, 2005). Children with OWB are at an increased risk of MSK disorders such as slipped capital femoral epiphysis, Blount's disease (deformity of the tibia), and *pes planus* (flat feet) due to increased mechanical loading on an immature, developing skeleton (Chan & Chen, 2009). This excess weight also alters movement patterns, exacerbating malalignment and contributing to pain in the lower back, feet, and knees (Shultz, Anner, et al., 2009; Stovitz et al., 2008).

During growth, adequate mechanical loading from PA is essential for bone development, with active children accruing significantly greater bone mineral content (BMC; 2198 ± 341g) compared to inactive peers (2104 ± 395g; Bailey et al., 1999). However, immature skeletal structures are particularly vulnerable to excessive forces from excess mass and poor movement patterns (Chan & Chen, 2009). Childhood OWB has long-term implications for MSK health, increasing the risk of knee pain and dysfunction in adulthood, with a higher relative risk (RR = 2.42, 95% CI 1.06 to 5.53) observed when OWB persists into adulthood (Antony et al., 2015b, 2015a). Carrying excess weight can lead to adverse MSK outcomes, such as pain (Section 1.2.2), therefore reducing quality of life (Section 1.2.3), PA (Section 1.2.4) and physical function (Section 1.3), which may further impact joint health as they grow and develop into adulthood (Antony et al., 2015b). These issues underline the importance of addressing OWB early to mitigate its impact on MSK health as well as the psychological and physiological effects.

1.1.7 Child overweight and obesity summary.

Rates of OWB remain high, and while the causes are complex, their impact on health well-being is well-documented (Chan & Chen, 2009; Omer, 2020; World Health Organization, 2016). The number of children classified as OWB by BMI has been steadily increasing both in the UK and globally. Although BMI is not a direct measure of adiposity, it serves as a useful tool for population tracking, with established associations between BMI and adiposity risk factors (Maximova et al., 2013). Assessing body composition in children with OWB is challenging due to growth but ADP and BIA are reliable methods when paediatric-specific equations are used. FM% thresholds are less commonly applied in children due to limited long-term health data, BMI-Z-scores remain the standard for classifying weight status in children. Children with OWB face a significant risk of developing obesity-related diseases, such as CVD and metabolic syndrome, as they grow (Figure 1-4). Childhood obesity can lead to long-term MSK issues and negatively impact physical well-being and physical function (as discussed in Sections 1.2 and 1.3), highlighting the importance of early intervention to prevent the consequences of OWB in children.

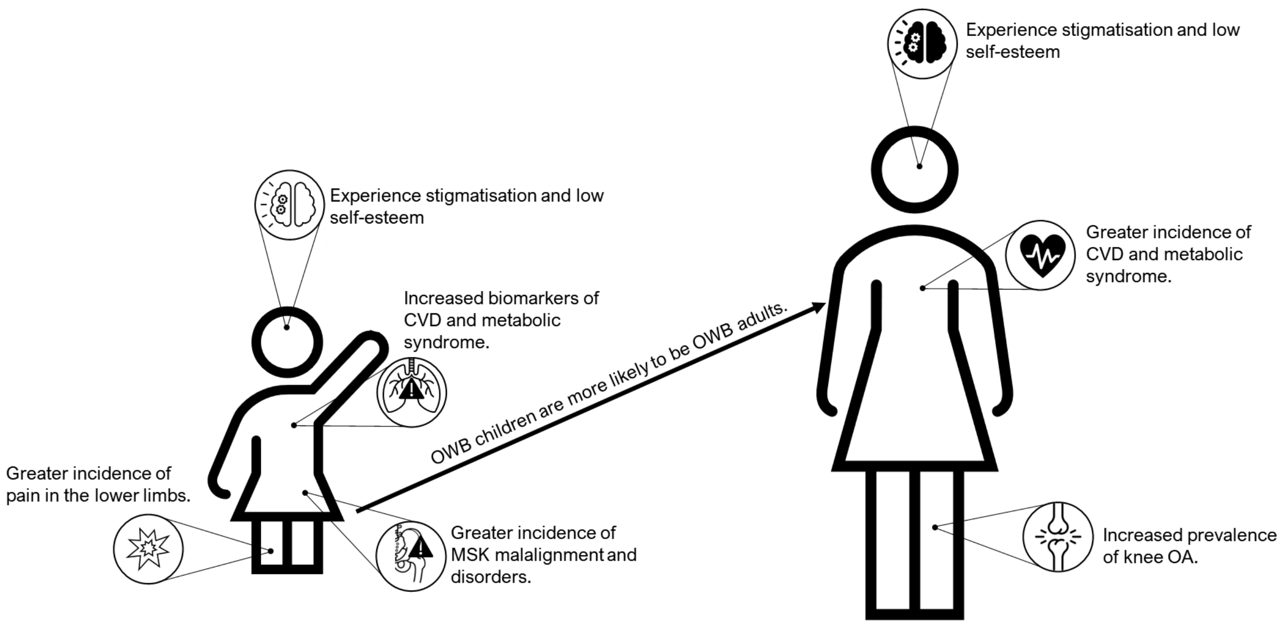

Figure 1-4 Summary schematic of the impact of OWB on children and potential to health and possible impact later in adulthood life.

1.2 Physical well-being

This section defines physical well-being and discusses the methods used in measuring pain, quality of life and PA in current research. The current findings in children with OWB for pain, quality of life and PA are presented, and how each of these components of physical well-being relates to one another. Lastly, this section discusses how each of these factors may interact with excess mass in children and the impact this may have on physical well-being and physical function.

1.2.1 Physical well-being definition

Pollard and Lee (2003) distinguished five domains of well-being: physical, psychological, cognitive, social and economic. Whilst all domains may interact with childhood obesity either as potential causes of increasing excess mass or as domains that OWB may impact; several of these domains fall outside the scope of the current work for possible intervention focus. Therefore, this section focuses on the physical domain of well-being in children with OWB. Physical well-being may be characterised by positive or negative indicators such as healthy behaviours (e.g. PA), nutrition (i.e. access to and consumption of healthy balanced foods), presence or absence of illness and symptoms (e.g. pain and quality of life), and abuse (Pollard & Lee, 2003). Within this thesis, physical well-being is a term used to summarise three components to be measured in response to an exercise intervention: pain, quality of life, and PA.

1.2.2 Self-reported Musculoskeletal Pain in Children

Pain is an unpleasant sensory and emotional experience associated with actual or potential tissue damage (World Health Organisation, 2021). Pain negatively impacts children's emotional, physical, and social development and function. Measuring pain, particularly in children, requires comprehensive assessments of intensity, quality, duration, and sensory characteristics to quantify this multidimensional phenomenon (Jain et al., 2012).

1.2.2.1 Measuring pain in children

Pain measurement in children requires a multifaceted approach involving various quantifiable measures. Available tools for measuring pain in children include self-reports, behavioural observations, physiological responses, or a combination of these (Jain et al., 2012). Behavioural measures prove particularly valuable for young or non-verbal children, while physiological indicators, such as heart rate, blood pressure, and vagal tone, offer insights into the body's response to pain stimuli (Jain et al., 2012). Self-report tools are considered the gold standard to quantify pain, with children's ability to report pain intensity and quality improving with age and development, typically becoming reliable around 7-to-8-years-old (Manworren & Stinson, 2016). Numerous instruments are available for measuring acute or chronic pain in child and adolescent age groups (Jain et al., 2012; Manworren & Stinson, 2016). Visual analogue scales (VAS) and numerical scales are effective tools for quantifying and assessing pain intensity in paediatric populations. (Manworren & Stinson, 2016). Some assessments to evaluate pain use a visual scale of faces (smiling to crying); however, these may confuse pain intensity for emotional expression (Manworren & Stinson, 2016). The Paediatric Pain Questionnaire (PPQ), developed by Varni et al. (1987), builds upon the widely used adult assessment tool, the

McGill Pain Questionnaire (Melzack, 1975), providing a reliable (test-retest ICC 0.40-0.85) and valid (convergent validity 0.27-0.68) measure of chronic pain intensity and quality of the MSK system in children (Cohen et al., 2008).

The PPQ assesses multiple dimensions of pain, including intensity, quality, and location (Varni et al., 1987). The self-report questionnaire consists of two VAS anchored by the descriptors: “Not hurting, No discomfort, No pain” and “Hurting a lot, Very uncomfortable, Severe pain”, to enable children to report *pain now* and *worst pain in the past seven days*. The VAS, suitable for children ages 5 and older, can be used for both acute and chronic pain assessments (Varni et al., 1987). In the third section of the PPQ, children report the location of pain by colouring various pain intensities on a body outline. The PPQ was first validated in 25 children and adolescents, 5 - 15 years, with juvenile rheumatoid arthritis against parent- and physician-assessed pain. Child-reported VAS scores for “pain now” were significantly correlated with parent (r = 0.72) and physician (r = 0.65) reported values (Varni et al., 1987). Correlations between child-reported and parent-reported “worst pain in the past seven days” was also significant (r = 0.54). However, parents and physicians rated children’s pain higher than children’s self-reported pain, particularly as pain ratings increased (Varni et al., 1987). The PPQ has been used to assess changes in pain in paediatric populations (Dhanani et al., 2002; Jacob et al., 2003). Dhanani et al. (2002) reported that in 533 paediatric rheumatology patients tracked across two time points, those that reported an improvement in quality of life (“*a little better*” or “*much better*”) saw a mean reduction in VAS pain of 0.82 and 1.45 cm. For patients who reported quality of life to be worse (“*a little worse*” or “*much worse*”) pain reported on VAS increased 1.90 to 3.69 cm (Dhanani et al., 2002). The PPQ has also been used to quantify pain in cross-sectional studies of obesity.

1.2.2.2 Pain reported in overweight and obese children.

Many cross-sectional studies have examined the prevalence of the presence of pain in children with OWB and adolescents, typically through medical records (Smith et al., 2014). The mechanisms of pain occurrence in children with OWB are considered to be through increased mechanical stress, particularly in the load-carrying limbs, and possible increased systemic inflammation, which has been exhibited in OWB adults (Tsiros et al., 2020; Vincent et al., 2015).The odds ratio (OR) of pain being present in the lower extremities increases with the presence of OWB and with greater obesity severity in children and adolescents (Adams et al., 2012; Bell et al., 2007; Krul et al., 2009; Taylor et al., 2006). Children and adolescents with OWB (data solely on children 7-11 years is not available) report significantly more MSK pain in the ankle and foot than TW 2-17- year-olds (OR = 1.92, 95%CI [1.15, 3.20]; Krul et al., 2009). The odds of pain in the lower limbs being reported significantly increases with obesity severity, from overweight (OR = 1.17, 95%CI [1.07, 1.28]) to obese (OR = 1.24, 95%CI [1.13, 1.35]) and to extremely obese (OR = 1.31, 95%CI [1.16, 1.48]) in 6-11-year-olds (Adams et al., 2012). Furthermore, Bell et al. (2007) report the OR of reporting pain with a one-point increase in BMI Z-score to be 2.54, regardless of weight status. However, in a similar cross-sectional study examining medical records, Bout-Tabaku et al. (2013) found no significant difference in BMI Z-score between obese 9-19-year-old groups where lower extremity pain was present and those where it was not, regardless of obesity severity. Similarly, in cross-sectional study of children with OWB self-reporting the frequency of pain, Lim et al. (2014) found there to be no significant difference in BMI Z-score of children with OWB who report “never” having pain, “almost never” or “sometimes” having pain, or those who reported “often” or “almost always” having pain in the last month, suggesting that OWB severity alone may not increase risk of experiencing MSK pain or there is a threshold effect of OWB impact on reported pain. Indeed Lim et al. (2014) and Bout-Tabaku et al. (2013) reported interactions of OWB with pain, quality of life, and PA, which will be discussed further in this chapter (Section 1.2.5).

As discussed earlier, pain is multidimensional and not only experienced as present or not; but the experience of pain differs in severity. In studies utilising the PPQ in children with OWB, differences in pain between TW and OWB groups or the relationship between pain and BMI have not been direct in causation and may be mediated by other factors such as physical function and PA (Tsiros et al., 2014, 2016). For example, Tsiros et al. (2016) reported that children (10-13-years old) classified as obese reported greater levels of “worst pain in the last seven days” than TW children (26 vs 19 mm, $p = 0.039$); whilst in the same cohort (two analyses from a larger study), Tsiros et al. (2014) reported no significant relationship between BMI and “current pain” ($r = 0.00$). However, the relationship between “worst pain in the last seven days” and BMI did become significant ($r = 1.38$) when factors such as household income, maternal education, and PA were controlled for in the regression analysis (Tsiros et al.,2014). Furthermore, Tsiros et al. (2016) found that “worst pain in the last seven days” significantly correlated with physical function ($r = -0.130$) and physical quality of life ($r = -0.297$). These findings further support the earlier findings from larger studies using medical records that the presence of OWB may increase the likelihood and severity of pain in children. Still, excess mass alone is not the only factor.

1.2.3 Health-Related Quality of Life

Within the WHO International Classification of Functioning, Disability, and Health (ICF), health-related quality of life (HRQoL) is defined as a subjective measure of well-being indicating how one feels about their health and consists of three main domains: physical, mental, and social (World Health Organisation, 2020). As discussed in Section 1.1.6, childhood obesity may impact all three domains of HRQoL, as those with obesity may experience poorer self-esteem and depressive symptoms, impacting mental well-being, and they may also experience stigmatisation and bullying, affecting social well-being (Creese et al., 2023; Kanellopoulou et al., 2022; Russell-Mayhew et al., 2012; Wardle & Cooke, 2005). Whilst both the mental and social domains of HRQoL are important factors for the overall well-being of children with OWB, interventions to affect these are outside the scope of the current thesis, and, therefore, within the current work, the focus will be given to the physical domain of HRQoL. The physical domain of HRQoL is concerned with the perception of physical functioning and the ability to perform and partake in activities of daily living, which are measured through self-report tools (World Health Organisation, 2020).

1.2.3.1 Measurement of physical HRQoL in children.

By definition, quality of life measures must be subjective (i.e. qualitative) and, therefore, are typically measured through questionnaires. Questionnaires to measure HRQoL in children may consist of either appropriate self-reports or parental proxy reports for children unable to read or write due to age or other conditions. Table 1-2 summarises the available HRQoL questionnaires and details the physical well-being or physical function domains captured by the tool. The Disabikids chronic generic measure (DCGM) physical domain focuses on condition-specific limitations, while *Sizing Me Up* emphasises body size, making these questionnaires less suitable for assessing children with OWB in non-clinical settings like schools, where stigmatization could occur (Creese et al., 2023; Fields et al., 2021). Only (paediatric quality of life inventory) PEDSQL 4.0 and KIDSCREEN include questions on participants' perception of PA and tasks of physical function. Moreover, PEDSQL 4.0 physical domain is strongly correlated with BMI (R^2 = -0.35) in children and adolescents with OWB (Zeller & Modi, 2009). Additionally, PEDSQL 4.0 exhibits greater internal consistency (Chronachs alpha [α] = 0.80) than KINDL-R (α = 0.56), the child health questionnaire (CHQ; α = 0.69), and DCGM (α = 0.76; Sandeberg et al., 2010; Eser et al., 2008; Raat et al., 2007; Varni et al., 2001). Considering the content and greater reliability of the PEDSQL 4.0, and its validation with children experiencing MSK problems, it presents as the most appropriate tool to asses physical HRQoL in a school-based exercise interventions.

1.2.3.2 Physical HRQoL in overweight and obese children.

In a systematic review of 34 studies, Buttitta et al. (2014) found that children and adolescents with OWB report lower HRQoL compared to TW peers and that greater obesity severity further reduced HRQoL. In the physical domain of HRQoL, OWB youth consistently scored lower than TW controls across various questionnaires (PEDSQL 4.0, CHQ, KIDSCREEN, and KINDL-R) in multiple countries, including the USA, Canada, Australia, Israel, Singapore, and across Europe (Buttitta et al., 2014). When examining HRQoL (PEDSQL 4.0) in UK OWB youth, young children (5-6 years old) do not demonstrate a significant effect of weight status (physical domain score not reported; Frew et al. 2015). Children with OWB 5-to-12 years old from clinical settings (hospital services) report significantly lower physical HRQoL (75%) compared to TW children (81.3%; Hughes et al., 2007). Indeed, the physical domain of HRQoL in the study by Hughes et al. (2007) was the only domain in the PEDSQL 4.0 to be significantly lower (73.3 vs 81.3%) in the OWB group compared to TW. Riazi et al. (2010) reported all domains, including the physical domain of the PEDSQL 4.0, to be lower in OWB (70.1 ± 17%) compared to TW (82.8 ± 12.4%). Moreover, differences in physical HRQoL (PEDSQL 4.0) seem to remain into adolescence (85.6 ± 18.1 vs 90.8 ± 14%) in UK OWB youth (Boyle et al., 2010). Additionally, HRQoL has been shown to be significantly (β=0.33) associated with PA levels (Gu et al., 2016).

Table 1-2 Overview of questionnaires available for measuring health-related quality of life in children.

Questionaire name	Report Types	Number of items	Recall period	Dimensions	Components of Physical dimension of largest item child report (responses available)
KIDSCREEN	Self report and Proxy versions	52, 27, and 10 items	Past week	Physical well-being Psychological well-being Moods and emotions Self-perception Autonomy Parent relations and home life Social support and peers School Environment Social Acceptance Financial resources	1) In general, how would you say your health is? (Excellent, very good, good, fair, poor) In the last week.. 2) Have you felt fit and well? 3) Have you been physically active (e.g. running, climbing, biking)? 4) Have you been able to run well? (not at all, slightly, moderately, very, extremely) 5) Have you felt full of energy? (never, seldom, quite often, very often, always)
The Child Health Questionaire (CHQ)	Child report (10-18 years) & parent proxy report	87 items	Most questions refer back to past 4 weeks	General health perceptions Physical functioning Role/social physical functioning Bodily pain Role/social emotional functioning Role/social behavioral functioning Parent impact-time Parent impact-emotional Self-esteem Mental health Behavior Family activities Family cohesion Change in health	1) Do things that take a lot of energy, such as playing soccer, running or hiking? 2) Do thing that take some energy, such as riding a bike or skating? 3) Walk several blocks or climb several flights of stairs? 4) Get around your school, neighbourhood, or playground? 5) Walk one block or climb one flight of stairs? 6) Do your tasks around the house? 7) Bend, lift, or stoop? 8) Eat, dress, bath, or go to the toilet by yourself? Get in and out of bed? (Yes very difficult, Yes somewhat, Yes a little difficult, No not difficult)
KINDL-R	Child report (4-16 years)	24 items	Past week	physical well-being emotional well-being self-esteem family friends everyday functioning in school Disease is an optional subscale	During the past week... 1) I felt ill 2) I had a headache or tummy-ache 3) I was tired and worn out 4) I felt strong and full of energy (never, seldom, sometimes, often, all the time)

Table 1-2 Continued

Questionaire name	Report Types	Number of items	Recall period	Dimensions	Components of Physical dimension of largest item child report (responses available)
Pediatric Qaulity of Life Inventory (PEDSQL) 4.0	Child repot (5-18 years) and parent proxy	23 items	Past month	Physical Emotional Social School functioning	In the past one month, how much of a prolem has this been for you... 1) It is hard for me to walk more than one block 2) It is hard for me to run 3) It si hard for me to do sparts activity or exercise 4) It is hard for me to lift something heavy 5) It is hard for me to take a bath or shower by my self 6) It is hard for moe to do the chores around the house 7) I hurt or ache 8) I have low energy (Never, Almost never, Sometimes, Often, Almost Always)
DISABKIDS chronic generic measure (DCGM)	Child report (8-16 years)	37 and 12 item versions	Past 4 weeks	Mental Social Physical	Think about the past four week 1) Are you able to run and move as you like? 2) Do you feel tired because of your condition? 3) Is your life rules by your condition? Does it bother you thst you have to explain to others what can and can't do? 4) Is it difficult to sleep because of your condition? 5) Does your condiction botehr you when you play or do other things? (never, sledom, quite often, very often, always)
Sizing me up	Child interview (5-13 years)	22 items	Past month	Emotional Functioning Physical Functioning Teasing/Marginalization Positive Social Attributes Mealtime Challenges School Functioning	During the past month, tell us how much you... 1) Found it hard to swing, climb, skip, bounce a ball, or jump rope because of your size? 2) Found it hard to keeo up with other kids because of your size? 3) Got out of breathe and had to slow down because of your size? (None of the time, A little, A lot, All of the time)

1.2.4 Physical Activity Behaviour

Physical well-being may be characterised by positive or negative indicators such as healthy behaviours (i.e. PA). PA is any movement that expends energy beyond that of resting, including activities of daily living (e.g., walking), play (activity done for its own sake voluntarily and for enjoyment), and exercise (planned activity with structure and purpose; World Health Organization, 2019). PA is a key healthy behaviour for physical well-being and development and is a fundamental component of the activities and participation domains of the International Classification of Functioning, Disability and Health Framework for Childhood Disability (Ross et al., 2016). PA may be defined by intensity, such as light activity (activities that do not get the child hot and breathless) or moderate-to-vigorous activity (activities that do get the child hot and breathless; MVPA). PA plays a crucial role in tackling OWB through its mechanism of energy expenditure and maintaining energy balance (Bülbül, 2019). Not only are higher PA levels associated with beneficial health outcomes irrespective of weight status (Gaesser & Angadi, 2021), but PA is a fundamental component of MSK development (Hills et al., 2007). Moreover, poor health, low levels of PA, and increased pain in children with OWB are associated with lower reported quality of life (Gu et al., 2016; Lim et al., 2014).

1.2.4.1 Measures of physical activity in children

Objective and subjective measurement techniques have been applied to capture and report PA levels in children. Subjective measurement tools such as activity diaries, questionnaires, and surveys are cost-efficient and have a low burden on the participants (Ellery et al., 2014). Questionnaires such as the PA for Older Children Questionnaire (PAC-Q) are valid and show good internal consistency in evaluating general PA in 8-13 years old (Crocker et al., 1997; Janz et al., 2008; Kowalski et al., 1997). However, subjective tools can be impacted by bias and limited by participants' ability to record or recall activity correctly (which may be age-dependent), and as such, typically overestimate PA levels compared to objective measures such as accelerometry or heart rate monitoring (Adamo et al., 2009). Moreover, whilst questionnaires provide an overview of general levels of PA, they do not capture the variable intensities and short sporadic bouts of activity seen in school-age children (Baquet et al., 2007).

Accelerometry, in contrast to questionnaires, offers an objective measure of movement intensity, frequency, and duration. Triaxial accelerometry can record body movement in all three planes and thus able to capture non-ambulatory activity, which may be more applicable to children's multi-directional, sporadic PA behaviour (Ellery et al., 2014; Gualdi-Russo et al., 2020). Raw acceleration signals from the movement of either uniaxial or triaxial units are translated to activity metrics of volume and intensity (Freedson et al., 2005) by counting total acceleration counts over a given time period (epoch) and applying thresholds to describe activity intensity (cut points). Cut points may define PA intensity (as sedentary, light, moderate or vigorous) according to given acceleration count thresholds (Table 1-3 and 1-4). The application of different epochs and cut points influences the calculated level of PA intensity and influences the relationship between PA and BMI, metabolic health, and motor skills (Aadland & Nilsen, 2022). Shorter epoch lengths typically show stronger relationships between PA and obesity measures (e.g. BMI, metabolic health) as short bouts of higher-intensity activity are captured, whilst larger epoch lengths average out these shorter bouts of activity (Aadland et al., 2020; Aadland & Nilsen, 2022). Table 1-5 shows the impact different epoch lengths have on the classification of time spent in sedentary and in MVPA behaviours. Children's PA throughout the day happens in sporadic and intermittent short bursts of ~10 s or less (Baquet et al., 2007). Aggregation of data over longer epochs (i.e. 30s or 60s) means activity at the upper and lower ends of intensity are essentially averaged over a longer period (Aadland et al., 2020). Therefore, short bouts of vigorous-intensity activity typically seen in children's activity behaviour may not be captured. However, in a systematic review of 28 studies of PA in children with OWB, the overwhelming majority (n = 17) applied 60s epoch with many (n = 6) not clearly stating, and few using 30s, 15s, and 10s (n = 1, n = 1, n = 2 respectively; Elmesmari et al., 2018). Despite the limitation in using larger epoch lengths, doing so may allow for better comparison to previous work. Moreover, despite the difficulty in drawing direct comparisons across studies with different epochs (and other methodological differences), Elmesmari et al. (2018) state that these differences had a limited probability of affecting differences in comparisons of levels of MVPA and sedentary behaviours between OWB and TW children and adolescents.

Table 1-3 displays the different cut points derived from calibration studies with Actigraph-made units and criterion methods. Most studies use indirect calorimetry, and activity cut-points are relative to the vertical axis of the accelerometer. Evenson et al. (2008) cut-points display better accuracy with indirect calorimetry in sedentary and vigorous activities compared to other available cut-points (receiver operating characteristic [ROC]-area under the curve [AUC] = 0.90, 95%CI [0.88, 0.91] and ROC-AUC = 0.84, 95%CI [0.82, 0.85] respectively) in children (Trost et al., 2011). Currently, there are no studies available for calibration in only children with OWB; however, the study from Trost et al. (2011), whose cohort was 26.2% OWB, concluded that Evenson et al. (2008) cut-points were most appropriate for children.

1.2.4.2 Physical activity levels in overweight and obese children.

Recommended PA levels for optimum health in 5-18-year-olds is a minimum of 60 minutes of MVPA per day, including activities to develop movement skills and muscle strength (UK Chief Medical Officer, 2019). Many (approximately 4 out of 5) children globally do not meet recommended PA guidelines regardless of weight status (Farooq et al., 2020; Keane et al., 2017). Longitudinal studies have demonstrated that the presence of OWB in children decreases levels of PA over time (de Jesus et al., 2021; Metcalf et al., 2011). MVPA has also been shown to decline throughout childhood; the greatest decreases are from age nine, suggesting that interventions to improve PA should occur during or before age 9 (Farooq et al., 2020). Compared to TW peers, children with OWB take part in less MVPA (Elmesmari et al., 2018; Page et al., 2005). Differences in MVPA between TW and children with OWB seem to occur during times when they have free choice over their activities, such as outside of the school day (Page et al., 2005). Time spent in MVPA is inversely associated with OWB, in that children with OWB do less activity (Keane et al., 2017). Conversely, when PA intensity is examined as light, moderate, or vigorous, only vigorous intensity activity levels are influenced by obesity (with vigorous-intensity exercise 20% less frequent in children with OWB), suggesting the lower level of MVPA in children with OWB compared to TW is driven by less frequent bouts of vigorous-intensity activity (de Jesus et al., 2021). Moreover, vigorous intensity PA has shown a greater association (than moderate or sedentary activity) with confounding factors of obesity rates (e.g. socioeconomic status; Bernhardsen, 2019; Love et al., 2019). However, what cannot be determined from these cross-sectional studies is causality (i.e. do children doing less PA become OWB, or do children with OWB become less active).

Table 1-3 Calibration studies for accelerometer physical activity intensity cut points in children.

Author	Participants	Criterion method	Activities	Accelerometer	Epoch
Evenson et al. (2008)	*n=33,* 5-8 years	Indirect calorimetry	Sitting, watching TV, colouring, slow walk, stair climb, dribble basketball, brisk walk, bicycling, jumping jacks, running	actigraph AM7164-2.2	15s
Freedson et al. (2005)	*n=80,* 6-18 years	Indirect calorimetry	Treadmill walk and run	actigraph model 7164	60s
Mattocks et al. (2007)	*n=163,* mean 12.4 years	Indirect calorimetry	Lying, sitting, slow walk, brisk walk, jogging, hopscotch	actigraph model 7164	60s
Puyau et al. (2002)	*n=26,* 6-16 years	Whole room respiration calorimetry	Video game, sitting and playing, walk, martial arts, moving and playing, jogging, skipping, jumping, soccer	actigraph model 7164	60s
Treuth et al. (2004)	*n=74,* 13-14 years	Indirect calorimetry	Rest, watching TV, video game, sweeping, slow walk, brisk walk, step aerobics, bicycling, shoot baskets, stair walk, run	actigraph model 7164	30s

Table 1-4 Comparison of physical activity intensity cut points in children.

	Sedentary	Light	Moderate	Vigorous	MVPA
Evenson et al. (2008)	≤25 (≤100)	26–573 (101–2295)	574–1002 (2296–4011)	≥1003 (≥4012)	≥574 (≥2296)
Freedson et al. (2005)	≤100	101–2391	2392–4382	≥4382	≥2392
Mattocks et al. (2007)	≤100	101–3580	3581–6129	≥6130	≥3581
Puyau et al. (2002)	<800	800–3199	3200–8199	≥8200	≥3200
Treuth et al. (2004)	<50 (<100)	51–1499 (101–2999)	1500–2600 (3000–5200)	>2600 (≥5200)	≥1500 (≥3000)

Note: MVPA: Moderate to vigorous physical activity. *Cut points are given in epochs of the study, values in brackets are adapted to 60s epochs for comparison.

Table 1-5 Effect of different epoch lengths applied to physical activity data on the amount of Sedentary and Moderate to vigorous physical activity *

Author		Epoch			
		1sec	10sec	15sec	60sec
Aadland et al. (2019)	SED (% of wear time)	75.09	61.64	-	48.99
	MVPA (% of wear time)	9.58	9.31	-	8.16
Banda et al. (2016)	SED (% of wear time)	77.63	62.89	59.95	48.92
	MVPA (% of wear time)	7.63	6.92	6.56	5.13
Froberg et al. (2017)	SED (% of wear time)	76.19	66.79	64.64	56.07
	MVPA (% of wear time)	7.98	7.34	7.26	6.43

Note: MVPA = Moderate to vigorous physical activity, SED= Sedentary activity, * all studies collected data from hip-worn accelerometers over seven consecutive days and applied Evenson cut points to threshold levels

1.2.5 Relationships between pain, physical health related quality of life and physical activity in overweight and obese children.

Several studies have examined the relationships between OWB, pain, physical HRQoL, PA and the associated mediating effects in children (Bout-Tabaku et al., 2013; Hainsworth et al., 2009; Lim et al., 2014; Tsiros et al., 2014, 2016). Physical HRQoL appears to be lower in those experiencing pain. Bout-Tabaku et al. (2013) found that obese 8-19-year-olds experiencing pain in the lower limbs reported significantly lower physical function HRQoL (PEDS-QL score 72.4 ± 17.1 vs 79.5 ±15.0 %). Tsiros et al. (2016) reported significant correlations (r = -0.297) between "worst pain in the last week" and physical HRQoL in OWB 10-13-year-olds. The presence of both OWB and pain together impairs physical HRQoL more so than just pain (OR = 2.3, 95%CI [1.1, 4.8]) or just OWB (OR = 6.6, 95%CI [3.0, 14.5]) alone (Hainsworth et al., 2009). The impact of pain on PA appears to be more complex than with HRQoL. Tsiros et al. (2016) reported no significant correlation (r = -0.04) between "worst pain in the last week" and PA (average counts/hour) in OWB 10-13 year-olds, whereas Wilson et al. (2010) reported that pain intensity was significantly explained (β = 0.39) by child-reported PA limitations due to pain (measured by questionnaire interviews). Objective PA levels were not recorded by Wilson et al. (2010) for comparison, but these findings may suggest that children perceive pain to limit their ability to perform PA, but pain does not impact total activity levels. However, Lim et al. (2014) reported that children with OWB with a low frequency of pain ("*almost never*" or "*sometimes*" experiencing pain) performed significantly less self-reported moderate PA (49.89 ± 47.73 minutes/day) than those who reported no pain (73.88 ± 76.2 minutes/day). Conversely, whilst it may be expected that higher pain frequency (experiencing pain "*often*" or "*almost always*") may also reduce moderate PA, Lim et al. (2014) found the low-frequency pain group did less PA (than no pain and high-frequency pain), with no difference in PA levels between the no pain and high-frequency pain groups. Lim et al. (2014) note that these findings may be impacted by the low number of children classed as having high-frequency pain (n = 20) compared to the low-frequency (n = 143) and no-pain (n = 107) groups.

PA as a healthy lifestyle behaviour is believed to be an important factor in HRQoL of children (Chen et al., 2005). With regard to children with OWB specifically, the relationship between PA and HRQoL may not be direct. For instance, whilst Tsiros et al. (2016) reported a significant correlation (*r* = 0.225) between physical HRQoL and objective measures of PA, the relationship between HRQoL and PA in children with OWB is mediated by FM% and cardiovascular fitness (VO^2 peak relative to mass). Shoup et al. (2008) reported that physical HRQoL was significantly different between children with OWB who met PA (PEDS-QL score 81.5 ± 16.3%) recommendations and those who did not (74.3 ± 16.2%), suggesting that weight status or PA alone does not account for the difference in physical HRQoL. In obese 5-9-year-olds, Morgan et al. (2008) reported that neither MVPA, vigorous PA, nor total activity counts were correlated with physical HRQoL. In fact, significant correlations with activity level were found only for age (*r* = -0.38 to -0.75) and motor skills (*r* = 0.28 to significant correlations withactivity level were found only for age0.53).

The link between low PA, poor physical function and resultant impact on health in children has been summarised in the literature as a cycle of negative events (Faigenbaum et al., 2018, 2023). Theorised models such as the inactivity triad and cascade of adverse outcomes resulting from poor muscular strength theorise the links between a lack of physical function (namely muscular strength) and diminishing physical well-being (Faigenbaum et al., 2018, 2023). While cross-sectional studies have suggested associations between physical well-being and physical function in children with OWB (Tsiros et al., 2016), further investigation into the effects of interventions on physical well-being is required to elucidate these relationships more comprehensively.

1.2.6 Summary of Physical Well-being

Physical well-being (here defined as pain, physical HRQoL, and PA) is negatively impacted in children with OWB. Figure 1-5 presents a schematic of the interacting components of excess mass and physical well-being in children with OWB. Studies show that children with OWB are more likely to experience pain, particularly in the lower extremities, with the odds of pain increasing with obesity severity. Although children with OWB report more MSK issues, some studies found no significant difference in pain frequency based on BMI alone, suggesting that other factors also contribute to reported pain. Studies have found that children with OWB report lower physical HRQoL compared to TW peers. Children with OWB engage in less MVPA than their TW peers, and children with OWB experiencing pain report lower physical HRQoL. The combined presence of OWB and pain more severely impairs physical HRQoL compared to either condition alone. The impact of pain on PA in children with OWB may be impacted by weight status. Additionally, children with OWB may perceive pain to limit their ability to perform PA, but different methods of recording pain and PA data make it difficult to draw conclusions. PA appears to be important for physical HRQoL in children with OWB, but the relationship between PA and physical HRQoL is likely not direct and affected by and related to other factors associated with OWB, such as physical function.

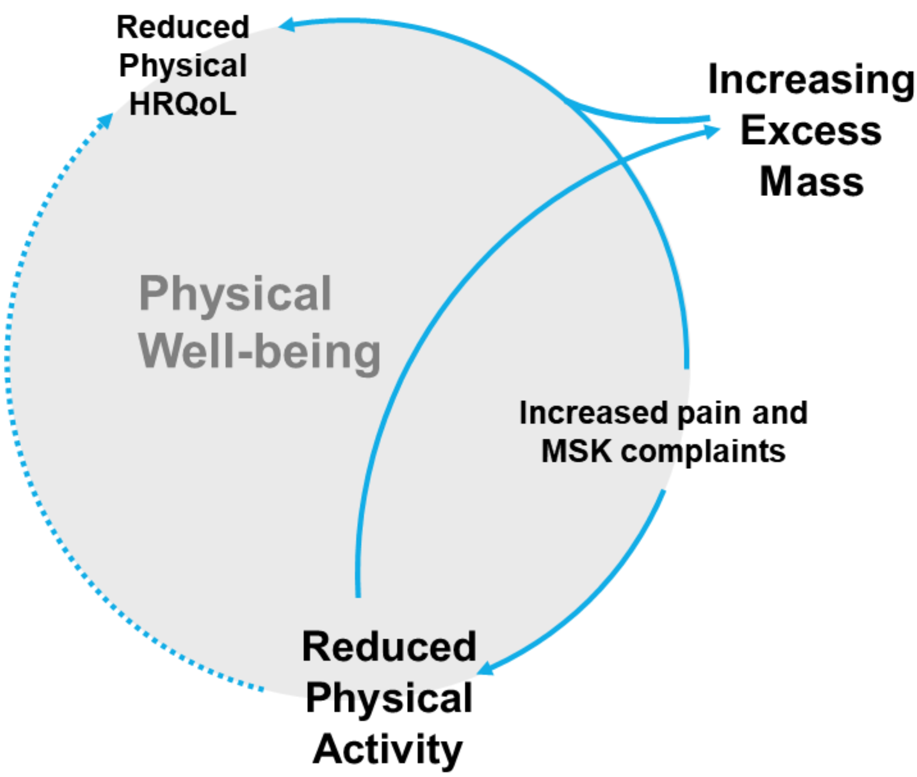

Figure 1-5 Summary schematic of interacting factors of physical well-being and excess mass in children.

1.3 Physical function

This section defines physical function and explores the components of physical function that are impacted by OWB. This section also details clinical and laboratory-based methods to assess physical function in children and identifies knowledge gaps in population-specific reliability and change statistics. 3D gait analysis is also presented as a detailed biomechanical view of a fundamental physical function task of daily living. Differences in gait biomechanical measurements between OWB and TW children are discussed. Finally, this section summarises the cyclical interaction of physical function and physical well-being in children with OWB and why components of physical function present as an ideal intervention point to disrupt this negative cycle.

1.3.1 Physical Function

Physical function is the capacity to perform tasks of everyday living, such as standing from a chair, walking, and balancing (Cooper et al., 2011). The ICF Disability and Health Framework (World Health Organisation 2007) defines dysfunction (disability) as impairments to body function (physiological function) or body structure (anatomical parts). Dysfunction limits activities (such as walking) or restricts participation in life situations (e.g. taking part in Physical Education [PE]). Impairments to body structure and function (the mechanisms of which are discussed further in this section) impact capacity and performance in physical tasks. Childhood obesity is associated with physical functioning deficits set out by the ICF framework (Tsiros et al., 2011, 2020). Physical function deficits include impaired cardiorespiratory fitness and motor task performance, as well as decrements in muscle function, gait, and balance (Forhan et al., 2013; Tsiros et al., 2020).

Understanding motor skills and motor control is key to examining physical function deficits in children with OWB, as these skills are foundational to everyday tasks. Motor skills are categorised as fine (involving small muscles such as pointing, placing, or grasping) or gross (large whole-body movements such as walking, jumping, or kicking). These skills are learned and mastered through childhood and adolescence in a hierarchical order from reflexes to fundamental motor skills (FMS; i.e. balancing, running, leaping, jumping, hopping, galloping, skipping, bouncing, throwing, catching, and kicking) to more specialised skills (e.g. dancing or climbing; Seefeldt, 1980). Skill level at each stage is dependent on optimal levels of achievement at each previous level (Logan, 2011), with children progressing through each stage through growth, maturation, and experience. Motor control is the initiation and regulation of voluntary movement by a complex network of feedback loops and reflexes in the central and peripheral nervous systems. Sensory input for these feedback loops comes from proprioceptors (inside the body) and exteroceptors (outside the body; Glazier & Davids, 2009). The complex interaction of systems, as well as the magnitude and timing of reflex responses, allows for the successful coordination of muscle groups to facilitate joint rotation and joint stiffness, creating coordination between limb segments and the environment. This organisation of muscle action, timing and sensory feedback generates movement and the successful completion of a motor task (Figure 1-6.).

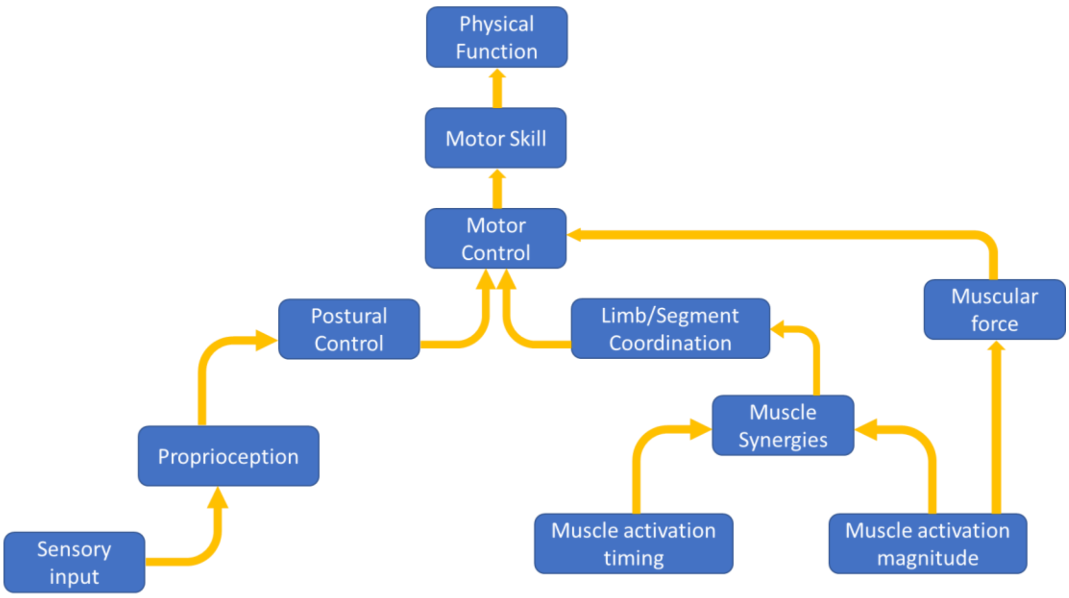

Figure 1-6 Schematic of components of physical function and organisation of bodily systems to achieve motor control (Latash, 2012).

Motor skills are assessed through standardised battery tests whereby children are scored on their ability to efficiently complete motor tasks such as running, hopping, catching, and throwing. Children with OWB demonstrate suboptimal motor skill levels compared to TW peers (Logan, 2011), and lower body weight predicts higher motor skill scores (D'Hondt, Deforche, Vaeyens, et al., 2011). Furthermore, children with OWB exhibit motor skills that are not just worse than TW peers but that are poor enough to be defined as motor-impaired (as defined by a score <15th percentile of a standardised distribution; D'Hondt, et al., 2011). FMS test batteries are reliant on the interaction of systems for adequate postural stability, muscular strength and coordination (Figure 1-6) to be competently performed (Marinšek et al., 2019). Global performance measures such as FMS tests provide a broad evaluation of ability, while detailed analyses of technique provide insights into the underlying mechanisms contributing to performance. Effective exercise intervention requires a targeted approach to components of physical function that are deemed to be impaired in children with OWB.

1.3.2 Postural stability

Postural stability involves compensatory and anticipatory muscle activity to maintain or achieve a state of balance by bringing the line of gravity (position of the centre of mass projected to the ground) within the base of support, the area directly beneath a person (Pollock et al., 2000). During tests of static balance, children reach adult ability levels at around the age of 7 years but on unstable surfaces with eyes shut, adult levels of balance are not reached until aged 12 years (Hsu et al., 2009). In laboratory settings, postural stability is assessed by measuring the displacement (maximal distance or total path length) or velocity of the centre of pressure (CoP), defined as the origin of global ground reaction force vector, or centre of mass (CoM) defined as the central point about which the mass is evenly distributed (Ruhe et al., 2010). Stability relies on CoP and CoM remaining within the base of support. Alternatively, functional balance tests (ability to balance during functional tasks) may infer postural stability.

1.3.2.1 Measures of Postural Stability in Children

Functional balance tests in children are tasks completed under altering constraints such as static tasks (e.g. single leg stance), dynamic tasks (sit-to-stand transitions or turning tasks) or locomotor tasks (e.g. tandem walking), several of which will also measure aspects of mobility and strength (Verbecque et al., 2019). Static tasks are limited in their applicability of understanding stability relative to functions of daily life. Moreover, whilst battery tests that incorporate dynamic and locomotor tests better reflect activities of daily living, performance in these tasks may be affected by strength, mobility and coordination (Clark et al., 2016; Marinšek et al., 2019). For example, jumping or hopping requires sufficient strength, and dribbling requires coordination between limbs and a ball. Therefore, measures of postural stability rather than inference through performance tests may better measure changes in postural stability from an intervention as it provides greater detail as to what is driving performance changes.

Tracking the position of the CoP or CoM allows for stability to be quantified. CoP and CoM measures may be taken during static and dynamic tasks using pedobarography (CoP only), force plates measuring 3D ground reaction force (GRF), or calculation of the CoM from segmental models. Greater velocities and excursions of CoP or CoM are associated with being less stable as these points move towards the outer bounds of the base of support and at quicker (less controlled) velocities (Riach & Hayes, 2008). CoP or CoM may be assessed during static bilateral or unilateral stance on surfaces of varying instability or during dynamic tasks requiring movement and control of the CoM, such as walking. Additionally, to further examine the ability of the different systems contributing to postural stability, senses such as vision, hearing, or plantar sensation may be omitted (Ruhe et al., 2010). Excess mass may increase the mechanical demand and constraints on systems to maintain postural stability, as previously discussed (King et al., 2012a; Mignardot et al., 2013; Sun et al., 2015).

1.3.2.2 Postural stability of overweight and obese children during bilateral stance

McGraw et al. (2000) found no significant difference between OWB and TW groups of children in CoP displacement during quiet standing. D'Hondt, et al. (2011) found CoP displacement (normalised to the duration of the trial, as it is expected that longer trials will incur longer path lengths) to not differ significantly between TW and children with OWB during bilateral stance with eyes open. Similarly, King et al. (2012) found no significant correlation between BMI (r =- 0.15), body mass (r = -0.16) or FM% (r = -0.12) with CoP displacement during standing. These findings suggest no effect of obesity on postural stability during quiet standing as CoP was not moving a greater distance over the base of support. However, Boucher et al. (2015) found obese children to have significantly increased CoP average velocity (obese:13.9cm/s vs 10.7cm/s and TW:16.7 vs 12.2cm/s for smaller and larger targets, respectively) during additional constraints of a fine motor aiming task (ability to move a stylus to a defined target zone) in which obese performed less well in both seated and standing conditions. Boucher et al. (2015) concluded that postural instability in obese children was affected by fine motor aiming. It is likely that bilateral standing with eyes open is a relatively simple task for both OWB and TW children to perform, explaining why significant differences were not found between groups (D'Hondt, et al., 2011; McGraw et al., 2000). Excess mass may, however, still apply additional demands on the postural stability system in these stable conditions to the extent that fine motor aiming task performance is affected through limb inertia and by increasing the demand on motor control systems. Additionally, OWB groups exhibit significantly greater variation in mediolateral stability measures (OWB: 20.25 ± 9.48% vs TW: 10.23 ± 1.00%) during bilateral stance, similar to that seen in younger age groups, suggesting that obese children are slower to develop mature postural stability compared to TW children (D'Hondt, et al., 2011; McGraw et al., 2000).

When the constraints of a bilateral stance task are altered, differences between OWB and TW groups are more prominent. McGraw et al. (2000) found that when vision is occluded, obese children have significantly increased mediolateral displacement of CoP during bilateral stance. Plantar sensory input may be impeded in children with OWB due to continuously increased loading and structural changes to the foot (Dowling et al., 2001; Riddiford-Harland et al., 2000). In children with OWB, lower plantar sensitivity is significantly correlated (r = -0.42) with increased maximal mediolateral CoP displacement (D'Hondt, et al., 2011). When plantar sensitivity is reduced (by ice application), there was no significant difference in CoP displacement between OWB and TW groups in eyes open or eyes closed conditions (D'Hondt, et al., 2011). These findings suggest a greater reliance on vision to maintain stability over other sensory input in children with OWB.

1.3.2.3 Postural stability of overweight and obese children during unilateral stance

During unilateral stance, King et al. (2012b) found significant correlations between CoP displacement and FM% (r = 0.25). King et al. (2012b) also reported knee strength to negatively correlate with CoP displacement (r = -0.30, in boys only) and strength relative to whole body moment of inertia to have moderate negative correlations with the standard deviation of the mediolateral path (r = -0.21 in boys and r = -0.42 in girls). Correlations between strength measures and stability measures suggest that children with OWB are not strong enough relative to their body size to maintain the same levels of postural stability as their TW peers; this is evidenced in poorer functional performance in balance tasks (Graf et al., 2004; Häcker et al., 2017; Merder-Coşkun et al., 2017; O'Malley et al., 2012). In static one-legged standing tasks, children with greater mass (TW vs overweight and obese vs severely obese) maintain balance for significantly less time in eyes open and eyes closed conditions (Graf et al., 2004; Häcker et al., 2017; Merder-Coşkun et al., 2017; O'Malley et al., 2012). One-legged standing is a static task that, as skills develop and children age, reaches a ceiling effect of the test time limit (120 to 180s); therefore, identifying motor control differences between OWB and TW groups as children age and develop is likely to become more difficult (Condon & Cremin, 2014). Furthermore, static tests are less applicable to the dynamic everyday tasks that children perform. To better understand the effects of being OWB on children's stability, tests may need to incorporate more challenging task constraints similar to those faced in real-life physical activities (Condon & Cremin, 2014).

1.3.2.4 Postural stability of overweight and obese children during dynamic tasks

Dynamic tasks such as rising from a chair or walking, increase demand on the neuromuscular systems maintaining postural stability as the CoM moves and lower limbs alternate between unilateral and bilateral stance. Obese children exhibit altered movement strategies that increase CoP excursion (maximum distance from central origin) and CoP velocity during dynamic tasks, reducing their overall stability (Hung et al., 2017). Deforche et al. (2009) reported that obese boys have significantly increased centre of gravity (i.e. CoM within assumed constant gravitational field) sway (movement of body's centre to maintain balance) velocity (OWB: 5.19 ± 0.9 vs TW: 4.19 ± 1.1 °/s) and increased weight transfer time (OWB: 0.45 ±0.60 vs TW: 0.21 ± 0.16s) in a sit-to-stand task compared to TW boys, suggesting that children with OWB struggle to control whole-body motion. CoP measures only explain 12% of whole-body postural stability mechanisms (Tisserand et al., 2023). As discussed in Section 1.3.5, children with OWB may adopt compensatory strategies involving the ankle and hip that are not fully captured by the foot-ground interaction assessed through CoP measures. While CoP measures provide valuable insights into stability, they do not quantify the underlying mechanisms controlling stability. In this context, 3D motion analysis of joint mechanics can complement CoP data by offering a more comprehensive evaluation of the biomechanical mechanisms used to maintain stability during movement.

1.3.2.5 Mechanisms of postural stability in overweight and obese children

The greater whole-body inertia experienced by those with a larger mass may negatively affect children with OWB's ability to maintain postural stability as more mechanical work is required. King et al., (2012a) examined the correlations between measures of stability, strength, and whole-body moment of inertia in 125 adolescents. King et al. (2012a) found that whole body moment of inertia was significantly correlated with body mass (r = 0.89, 0.95), BMI (r = 0.98, 0.61), and FM% (r = 0.42,0.30) in boys and girls, respectively. Whilst it is clear that OWB increases whole body moment of inertia, which affects postural stability in dynamic tasks, static balance tasks do not require the same demands to control CoM motion; therefore, the increased moment of inertia may not be the sole explanation for poorer postural stability. Reduced plantar sensitivity in OWB has been a proposed mechanism for the reduction in postural stability (McGraw et al., 2000). However, despite a correlation (r = -0330 - -0.42) between plantar sensitivity and postural stability (CoP velocity and mediolateral excursion) in obese children, differences in postural stability between OWB and TW remained after postural sensitivity was reduced, suggesting other or additional mechanisms to reduced postural stability in children with OWB (D'Hondt et al., 2011).

Proprioception is the awareness of joint movement and position, involving the ability to sense body segment movement and position through neuromuscular signals (Han et al., 2016). Tests for proprioception include measuring thresholds for passive movement, assessing the ability to reproduce joint positions, and judging segment positions based on past experiences (Han et al., 2016). No differences in proprioception between OWB and TW children (6 years old) have been found, likely because the proprioceptive system is still developing at this age (Shumway & Woollacott, 1985). When comparing knee reposition error and passive motion sense in knee flexion, 8-12-year-old children with OWB perform less well compared to TW children (Saleh et al., 2018; Wang et al., 2008). Proprioceptive deficits may impact movement patterns. Hung et al. (2017) found children with OWB to have significantly less knee flexion during a standing pick-up task, opting for greater sagittal plane spine excursion to complete the task and shifting the CoM position more anteriorly. Furthermore, children with OWB walk with less knee flexion during gait (Molina-Garcia et al., 2019). These altered movement patterns may be a result of altered knee function because of poorer proprioceptive abilities in children with OWB around the knee joint.

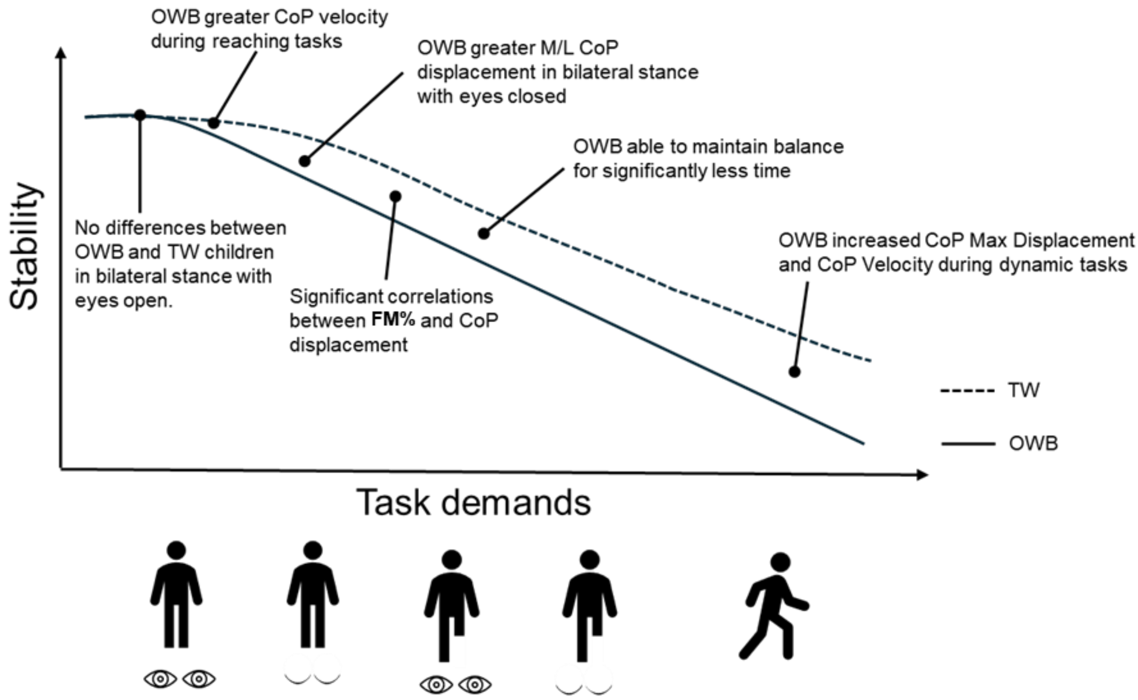

Figure 1-7 Summary of postural stability findings on children with OWB.

Note: OWB = Overweight and obese children; TW = Typical weight children, M/L= mediolateral; CoP = centre of pressure; FM% = Fat-Mass percentage.

1.3.2.6 Postural Stability Summary

Figure 1-7 summarises the key concepts and findings of postural stability in children with OWB relative to TW children. The greater postural instability in children with OWB in unilateral standing likely explains the poorer performance of children with OWB in single leg stance (SLS) tests (Graf, et al., 2004; Häcker et al., 2017; Merder-Coşkun et al., 2017; O'Malley et al., 2012). Additionally, during dynamic tests, postural stability appears to be impaired, whilst also exhibiting different movement strategies to handle the demands of the task (Deforche et al., 2009; Hung et al., 2017). Bilateral stance is a relatively stable position and may not be challenging enough to show differences between OWB and TW children, whilst more challenging unilateral tasks are more demanding on postural stability, static measures are not comparable to the dynamic movements of daily activities such as walking. Postural stability should be examined during a dynamic everyday task to understand how exercise interventions may improve physical function. Moreover, many studies have examined CoP measures which reflect the foot-ground interaction rather than whole-body movement, which may be better represented by CoM displacement and velocity. The distinction between foot-ground interaction and whole-body movement may be particularly important when considering the altered body mass distribution in children with OWB.

1.3.3 Muscular strength

Muscle strength is an important component of physical function, and strength measurements are widely used in clinical and laboratory settings (Jones & Stratton, 2000). Strength is defined as the maximum force a muscle or muscle group can exert during voluntary contraction (Jones & Stratton, 2000). Muscle fibre type distribution and structural properties reach adult levels by age 6 years (Bell et al., 1980). However, the ability to produce the same muscular force compared to muscle cross-sectional area is lower in children and in females (Kanehisa et al., 1994), likely due to the lower motor unit activation seen in children compared to adults (Dotan et al., 2012). Assessment of muscular strength in children is typically performed under isokinetic, isometric, or isotonic conditions, and the method of testing should reflect the purpose of the assessment (Jones & Stratton, 2000). Methods to assess strength in children include jump tests, hand grip strength, one repetition maximum (1RM), hand-held dynamometry and isokinetic dynamometry (Table 1-6).

Jump tests measure aspects of function, such as power, from which strength may be inferred. Children with children consistently exhibit poorer performance in jump tasks compared to TW children (TW = 65.45, OW= 60.0, OB= 55.4 cm+qualitative score; Chivers et al., 2013). Children OWB perform less well in motor tasks that require lifting and propelling the body against gravity due to carrying excess mass. Furthermore, during jumping tasks, children with OWB exhibit jump movement patterns characteristic of earlier developmental stages compared to TW peers (Cowley et al., 2020). Therefore, jumping performance may not be an optimal measure of absolute strength in children with OWB due to the constraint of excess mass and the demands of a gross motor skill such as jumping. Grip strength appears to be significantly greater in children with OWB (OWB = 175.3 ± 37.2 vs TW = 147.6 ± 34.8 N; Ceschia et al., 2016). Whilst grip strength is strongly correlated (r = 0.74 to 0.90), depending on gender and hand dominance) with total muscle strength (sum of shoulder, hip flexion and ankle dorsiflexion) in children and adolescents, when body weight is controlled for the correlation is weaker (r = 0.485 to 0.564; Wind et al., 2010). Furthermore, Wind et al. (2010) reported substantial inter-individual inaccuracy (standard error 60.7 N for girls, 81.5 N for boys) in the prediction of total muscle strength from grip strength. Hand grip strength cannot infer individual muscle group or limb contributions to strength and function. Alternative methods such as one repetition maximum (1RM) test, hand-held dynamometry (HHD), and isokinetic dynamometer are able to provide information on individual limbs or muscle groups.

1RM tests for leg press and leg extension have been shown to be safe in healthy children (6.2 to 12.3 years) after initial introductory sessions to teach participants controlled movement and breathing (Faigenbaum et al., 2003). 1RM leg press is significantly correlated with BMI in 7-12-year-old children (r = 0.59) but significantly negatively correlated (*r* = -0.31) with BMI when 1RM leg press is relative to body weight (Milliken et al., 2008). However, 1RM tests may be challenging for children with OWB who exhibit poor motor skill or immature movement patterns, and 1RM tests are only able to measure strength at the weakest point of a participant's range of motion (Jones & Stratton, 2000). Furthermore, 1RM tests rely on movement skills, which improve most when training mirrors the test movement (Buckner et al., 2017). As a result, strength gains from interventions that differ from 1RM tests motor pattern, may be underrepresented or overlooked (Buckner et al., 2017). HHD requires participants to exert maximum force against the dynamometer while the examiner holds a position (the make test) or the examiner applies sufficient resistance to overcome the participants' maximum force (break test; Jones & Stratton 2000). It is suggested that the break test may induce pain and, therefore, be inappropriate for children (Jones & Stratton, 2000). HHD shows good concurrent validity (ICC >0.78) compared to isometric measures taken from gold standard isokinetic dynamometry in lower limb muscle groups in adolescents (Hébert et al., 2011). However, relative to isokinetic dynamometry, HHD may underestimate torque in children with higher torque values (Mahaffey et al., 2022). Furthermore, HHD assessment of strength is static and does not quantify strength over an entire range of motion, and therefore, the joint angle at which peak torque is produced could potentially be missed.

1.3.3.1 Isokinetic Dynamometry

Isokinetic dynamometry is considered the most valid tool for measuring muscle strength (Jones & Stratton, 2000). Whilst isokinetic dynamometry is not portable and is more expensive than other measures previously discussed, it allows for the safe assessment of maximal strength through a dynamic range of motion (Hill et al., 1996; Jones & Stratton, 2000). Isokinetic dynamometry offers an assessment of muscular strength in isolated joints across a range of contraction types (concentric, eccentric, isotonic) and velocities.

1.3.3.1.1 Reliability of isokinetic dynamometry in children

In a meta-analysis of the reliability of isokinetic dynamometer assessment of knee strength in paediatric populations (healthy, athletic, and with cerebral palsy), isokinetic dynamometry was highly reliable for knee flexor (ICC = 0.84) and knee extensor (ICC = 0.90) torque (Muñoz-Bermejo et al., 2019). Reliability of isokinetic dynamometry of the knee is similar in children with OWB. Collado-Mataeo et al. (2020) reported excellent reliability (ICC > 0.956) for knee extension and flexion at 60deg/s in obese 6-11-year-olds. However, Collado-Mataeo et al. (2020) reported test-retest within the same session and not between sessions. Inter-session reliability of children with OWB is yet to be determined. Reliability was lower in knee flexion compared to knee extension across all three studies.

Burnett et al. (1990) reported moderate (ICC 0.63-0.68) reliability for hip extension and flexion and poor (ICC 0.49 – 0.55) reliability for hip abduction and adduction in 6-10-year-olds children. Some movements may be more challenging for children, and they may shift out of position during testing, leading to recorded torque that reflects not only the targeted muscle group but also contributions from other muscle groups (Burnett et al., 1990). Furthermore, Fagher et al. (2016), Deighan et al. (2003), and Burnett et al. (1990) used a range of testing velocities from 30°/s to 180°/s. Since different velocities trigger varying motor unit activation patterns, testing at different velocities results in different torque values within the same subjects, making comparison across studies difficult (Baltzopoulos & Brodie, 1989). When muscle strength is examined in relation to a specific activity, such as gait, it is, therefore, important that velocity protocols best reflect that of the movement (Baltzopoulos & Brodie, 1989). Therefore, it is important to determine the reliability of all lower limb muscle groups and velocities to be tested.

Table 1-6 Summary of strength measures in children with OWB, the reliability of measures and findings in children with OWB.

Strength Measure	What is measured.	Reliability	Findings in OWB children.	Considerations in OWB children.
Jump test	Jump height or distance, strength is inferred from muscular power (a product of force and velocity of action).	Standing long jump, squat jump and countermovement jump all have high test-retest reliability in TW children (ICC 0.94, 0.94, 0.95 respectivley) Fernandez-Santos et al. (2015).	Typically OWB children cannot jump as high or far as TW children (Dumith et al., 2010; Rauch et al., 2012).	OWB children perform less well in motor tasks that require lifting and propelling the body against gravity, due to carrying excess mass. OWB children exhibit jump movement patterns characterisitic of earlier developmental stage compared to TW peers (Cowley et al., 2020).
One repetition maximum	Maximal amount of weight lifted one repetition, may be a squat, leg press, chest press for example (Faigenbaum et al., 2003)	Test-retest reliability for chest press (0.98) and leg press (0.93) are excellent in TW children (Faigenbaum et al., 1998)	Obese significantly lower 1RM/BM leg press p=0.044 than overweight children. No difference in 1RM/BM bench press (Molina-Garcia et al., 2019). Significant positive correlations for absolute leg press 1RM and BMI in 7-12 year olds (Milliken et al., 2008)	1RM tests may be challenging for OWB children who exhibit poor motor skill/imature movement patterns (Jones & Stratton 2000). 1RM are only able to measure strength at the weakest point of a participants range of motion (Jones & Stratton 2000)
Grip strength	Maximum static force that the hand can squeeze, measured by dynamometer in kg, pounds, or N (Massy-Westropp et al., 2011). Tota body strength is then inferred	Test-retest reliability for grip strength in 7-12 year old children is excellent (0.95-0.98) (Dekkers et al., 2020)	Non-significant differences in weight status groups 8-12 years old (Miranda-Alatriste et al., 2024). Positive correlations found between BMI and absolute grip strength, but significant negative correlation with BMI for grip strength relative to BM children 7-12 years olds (Milliken et al., 2008)	Wind et al. (2010) reported substantial interindervidual inaccuracy (standard error 60.7 N for girls, 81.5 N for boys) in the prediction of total muscle strength from grip strength.

Table 1-6 continued Summary of strength measures in children with OWB, the reliability of measures and findings in children with OWB continued

Strength Measure	What is measured.	Reliability	Findings in OWB children.	Considerations in OWB children.
Hand held dynamometry	Isometric strength on isolated joints.	HHD isometric force has good inter and intra reliability (ICC >0.88) for lower limb groups (knee flexors, knee extensors, dorsiflexors, and plantarflexors) in children 5 to 15 years (Doloia et al., 2018).	Absolute isometicHHD hip and knee extension torque is significantly greater in OWB. IsometicHHD hip and knee extension torque relative to BM is significantly lower in OWB (Prasetiowati et al., 2017).	HHD may underestimate torque in children with higher torque values as expected from OWB children relative to TW (Mahaffey et al., 2022).
Isokinetic Dynamometry	Muscular strength in isolated joints across a range of contraction types (concentric, eccentric, isotonic) and velocities.	Excellent reliability (ICC>0.956) for knee extension and flexion at 60deg/s in obese 6-11-year-olds (Collado-Mateo et al., 2020). Moderate (ICC 0.63-0.68) reliability for hip extension and flexion and poor (ICC 0.49 – 0.55) reliability for hip abduction and adduction in 6-10year olds children (Burnett et al., 1990)	Typically OWB children exhibit greater absolute torque in lower limbs, these findings change with different scaling techniques and muscle groups (Theis et al., 2019).	Children are very unlikely to have experience with isokinetic dynamometry; therefore, familiarisation is an important consideration. Relability of a range of lower limb muscle groups not examined in OWB children.

1.3.3.2 Differences in Absolute strength between overweight and obese and typical weight children

When comparing absolute values of isometric knee extension torque in children and adolescents with OWB to TW groups, OWB are 5.7 to 25% stronger (Abdelmoula et al., 2012; Garcia-Vicencio et al., 2016; Maffiuletti et al., 2008; Theis et al., 2019; Tsiros et al., 2013). Adolescents (13-17 years) demonstrate an effect of muscle length as Maffiuletti et al. (2008) report OWB adolescents to be significantly stronger (+25%) in isometric knee extension torque at 40° of flexion but found no significant difference between OWB and TW groups for isometric knee extension torque at 80° of flexion. Maffiuletti et al. (2008) suggest the difference in strength findings at different angles may be a result of OWB reducing the flexion range of motion during daily tasks to limit stress to joints, therefore achieving a training effect at these limited ranges. However, the effect of muscle length does not appear to be replicated in younger children (9 to 13-years-old), as Blimkie et al. (1989) report no significant difference in isometric knee extension torque in 20° to 90° of knee flexion between OWB and TW children. In absolute terms, absolute isokinetic knee torque is typically 14-19% higher in children and adolescents with OWB compared to TW peers at 60°/s (Theis et al., 2019; Tsiros et al., 2013) and 180°/s (Maffiuletti et al., 2008). With regard to other lower limb muscle groups, only Theis et al. (2019) report comparisons between OWB and TW children in absolute terms and found children with OWB to be significantly stronger in isometric knee flexion (OWB +19%), isokinetic ankle dorsiflexion (OWB + 5.7%) and isokinetic knee flexion (OWB +14.9%). Greater muscle strength is considered a training effect of carrying a larger body mass (Tomlinson et al., 2016). Therefore, examining strength relative to body size may provide a greater understanding of functional deficits in children with OWB.

1.3.3.3 Differences in ratio scaled strength between overweight and obese and typical weight children.

When knee extension torque is ratio scaled to body mass, children and adolescents with OWB are significantly 24-25% weaker than TW counterparts in isometric and isokinetic tests (Abdelmoula et al., 2012; Blimkie et al., 1989). However, ratio scaling assumes a linear relationship between body mass and strength and does not account for the disproportionate mass relative to strength in children with OWB. Therefore, ratio scaling to body mass may overstate the difference in strength between OWB and TW groups. Knee extension strength ratio scaled to FFMkg was not significantly different between OWB and TW children and adolescents (Abdelmoula et al., 2012; Maffiuletti et al., 2008) suggesting that there was no difference in muscle function characteristics between OWB and TW children and adolescents. However, FFMkg estimates do not discriminate between muscle mass and other non-FM tissues, such as skeletal tissue. When strength is ratio scaled to lean mass (measured from DEXA scan), Abdelmoula et al. (2012) found that OWB adolescents remain significantly stronger (+21.8%). Garcia-Vicencio et al. (2016) found OWB adolescent girls to be stronger than TW girls in absolute terms but not when knee extension torque was normalised to segmental lean mass. Differences in muscle architecture, such as greater pennation angle (+20%) and muscle thickness (+30-50%) measured in OWB girls by Garcia-Vicencio et al. (2016), may account for some of the differences in strength in OWB and TW groups.

1.3.3.4 Differences in allometrically scaled strength between overweight and obese and typical weight children.

Allometric scaling is advantageous over ratio scaling because it does not assume a priori relationship between strength measures and body size (Wren & Engsberg, 2007). Isometric and isokinetic knee extension allometrically scaled to body mass is significantly lower in children and adolescents with OWB compared to TW peers by 10-15% (Theis et al., 2019; Tsiros et al., 2013). When isometric knee extension torque is allometrically scaled to FFMkg, children with OWB are 14.3% weaker than TW peers (Theis et al., 2019). However, Tsiros et al. (2013) conversely found no significant difference between OWB and TW children in allometrically scale to FFMkg isometric knee extension torque. The difference in reported findings between Tsiros et al. (2013) and Theis et al. (2019) are likely due to different methods to estimate FFMkg (DEXA vs ADP_{Lohman}). As discussed in Section 1.1.4.1.1, ADP_{Lohman} may underestimate FM% (therefore overestimated FFM) compared to the DEXA scan, therefore altering the relationship with relative strength. Other lower limb muscle strength allometrically scaled to body mass showed children with OWB to be weaker at the hip and ankle (Table 1-7). Allometrically scaled strength to body mass and FFMkg show the same trends as ratio-scaled strength between OWB and TW children, but mean differences appear smaller (Table 1-7), demonstrating how the assumptions of ratio scaling may misinterpret the relationship between strength and mass. Nonetheless, regardless of the scaling method, what is clear is that children with OWB are not as strong as TW children relative to their body mass. The greater strength exhibited by children with OWB compared to TW children in knee strength relative to FFMkg may be due to the greater pennation angle and muscle thickness in the quadriceps muscles as reported by Garcia-Vicencio et al. (2016), but the same training effect of carrying a larger mass is not evident on muscles at the hip. The difference in findings between the knee and hip may be due to movement patterns OWB have been reported to undertake that are protective of the knee but not the hip or ankle (DeVita & Hortobagyi, 2003).

1.3.3.5 Summary of muscle strength

Isokinetic dynamometry is reliable in children for strength assessment of knee extensors and flexors. However, data for muscle groups controlling the hip and ankle are limited. Children with OWB tend to be stronger in absolute terms compared to TW peers, possibly as a training response to carrying excess mass. However, relative to body mass, children with OWB tend to be weaker when ratio and allometrically scaled (Table 1-7). Lower strength relative to body mass suggests that children with OWB may not have adequate strength to be able to move and control their body mass as well as TW peers; therefore, limiting physical function. Examination of the reliability of a range of lower limb muscle groups in children with OWB is needed to determine the effectiveness of interventions designed to target relative muscle weakness related to functional deficits. However, muscle strength or postural stability alone does not define physical function; clinical measures from tasks of everyday living can capture broader information on the performance of daily living tasks.

Table 1-7 Differences in overweight and obese children compared to typical weight children for the lower limb in absolute, ratio and allometric scaled comparisons. Summary of findings from Section 1.3.4.3 to 1.3.4.4.

Category	Measure	Absolute	Body Mass Scaled (Ratio)	Body Mass Scaled (Allometric)	Fat Free Mass (Ratio)	Fat Free Mass (Allometric)
Knee Extension	Isometric	OWB +57 to 25.0%	OWB -24 to 25%	OWB -10 to11.7%	OWB +21.8%	OWB +14.3%
	Isokinetic	OWB +14 to19.0%	-	OWB -13 to15.0%	-	NS
Knee Flexion	Isometric	OWB +19.0%	-	-	OWB +11.6%	-
	Isokinetic	OWB +14.9%	-	-	-	-
Hip Extension	Isometric	NS	-	-	NS	-
	Isokinetic	NS	-	OWB -22.4%	-	OWB -28.6%
Hip Flexion	Isometric	NS	-	-	-	-
	Isokinetic	NS	-	OWB -26.5%	-	-
Hip Abduction	Isometric	OWB -17.6%	OWB -17.5%	-	-	OWB -25.0%
	Isokinetic	NS	-	-	-	-
Hip Adduction	Isometric	NS	-	-	-	-
	Isokinetic	NS	-	-	-	-
Ankle Plantarflexion	Isometric	NS	OWB -18.8%	-	-	-
	Isokinetic	NS	-	-	-	-
Ankle Dorsiflexion	Isometric	OWB +5.7%	OWB -20.1%	-	-	-
	Isokinetic	NS	-	OWB -14.7%	-	-

Note: OWB = Overweight and Obese, +% = stronger, -% = weaker, NS = non-significant differences, **-**= no findings reported

1.3.4 Clinical measures of physical function in children with overweight and obese children

In clinical practice and educational environments, the use of laboratory-based measures to assess aspects of physical function may not be available. Therefore, the use of clinical assessment tools to measure physical function allows for findings to be generalised to settings outside of the laboratory. In a review of the measurement properties of physical function performance measures in children with OWB, Mahaffey et al. (2016) identified 66 performance tests to assess flexibility, strength, aerobic performance, anaerobic performance, coordination, balance and motor skill. Of those tests, only the six minute timed walk (6MTW) had data for all psychometric measurement properties (construct validity, internal consistency, repeatability, and responsiveness) and was thus recommended as a measure of physical function in children with OWB (Mahaffey et al., 2016). It has also been recommended that a series of function tests be performed to understand muscle function and physical performance (in a range of populations), including locomotor and sit-to-stand movements and balance tests (Beaudart et al., 2019). In the following sections, clinical tests of physical function that are recommended for assessing muscle function and those commonly applied in children with OWB will be discussed.

1.3.4.1 Timed up and go test

Timed-up -and-go (TUG) mainly assesses strength, gait and dynamic balance by measuring the time a person takes to stand from a chair, walk 3 m, return and sit down again. In children (aged 3 to 9-years-old) without physical disabilities (performing the test three trials in a row), the TUG test showed good between-trial reliability (ICC 0.80, 0.89, 0.83) and good same-day retest reliability (ICC 0.89), with no difference between males and females (Williams et al., 2005). Similarly, Nicolini-Panisson and Donadio (2014) reported excellent same-day (ICC 0.93) and one-week (ICC 0.95) retest reliability for TUG tests in 3 to 18-year-olds. TUG tests 5 months apart showed a significant (p =0.001) change in score (5.7 ± 1.3s vs 5.2 ± 0.9s), suggesting the TUG test is also sensitive to change over time due to maturation (Williams et al., 2005).

Normative data for typically developing children and adolescents suggest an average TUG time of 5.61 ± 1.06s (Nicolini-Panisson & Donadio, 2014). Comparative studies show children with OWB perform less well in TUG tests than TW children (Table 1-8). Despite Tsiros et al. (2012) and Merder-Coskun et al. (2017) finding significant differences between OWB and TW groups in TUG times (Table 1-8), mean differences did not exceed the 2s clinically important difference suggested by (Nicolini-Panisson & Donadio, 2014). However, the 2s clinically important difference is based on data from typically developing children and adolescents and may not be representative of an obese pediatric population. Merder-Coşkun et al. (2017) studied a larger age range (6-15 years old), which may account for the larger standard deviations (Table 1-8). Compared to Tsiros et al. (2012) performance in TUG may be influenced by age and growth (Williams et al., 2005). Children with OWB may perform less well in TUG tests because of the increased demand on the lower limb to lift and control a larger body mass. Lower relative muscular strength and poor stability in OWB compared to TW children (Sections 1.3.2 and 1.3.2) may impede the sit-to-stand transition, walking, and turning phases, which appear slower in children with OWB (Cilli et al., 2021; Molina-Garcia et al., 2019).

Table 1-8 Studies comparing timed-up-and-go tests in typical weight, overweight and obese children.

	Age(yrs)	n	TUG time	Main findings
Itzkowitz et al. (2016)	5-11	TW n=939 OW n=241 OB n=234	TW 6.54 ± 1.13 OW 6.55 ± 0.99 OB 6.80 ± 1.09	Correlation of BMI and TUG time (r = 0.065). Comparison between groups non-significant.
Tsiros et al. (2012)	10-13	TW n=132 OB n=107	TW 7.2 ±0.1 OB 7.7 ± 0.1	A significant difference between groups
Meder-Coskun et al. (2017)	6-15	TW n= 25 OB n=193	TW 7.4 ± 1.2 OB 8.1 ± 3.9	A significant difference between groups

Note: OB = obese, OW = Overweight, TW = Typical weight

1.3.4.2 Single Leg Stance Test

The SLS test requires individuals to stand on one leg, hands on hips, and maintain balance for as long as possible. SLS tests have good test-retest reliability in eyes open (ICC 0.83) and eyes closed (ICC 0.86) conditions as tested in 49 typically developing 6-12-year-olds (De Kegel et al., 2011). Balance times in typically developing children are 10 – 75 s in 8-9-year-olds and 48 – 120 s in ten-year-olds (Condon & Cremin, 2014). Pathare et al. (2013) and Merder-Coşkun et al. (2017) found that children and adolescents with OWB balanced for a significantly shorter time than TW peers (Table 1-9). Similarly, Graf et al. (2004) reported a significant effect of weight status (obese, overweight, normal weight or underweight) on children touching their free non-standing leg with the ground during 1 minute of single-leg standing, suggesting poorer balance. Gray and Smith (2003) reported no significant relationship between SLS time and BMI in Native American youth. However, the lack of significance may be due to the large age range (5-18 years) and, therefore, range of balance ability, which may have had a greater impact on performance than BMI. Häcker et al. (2017) reported no significant difference between obese (97th BMI centile) and severely obese children (99.9th BMI centile), suggesting that balance performance may not worsen with the degree of obesity. The minimum clinically important difference for the one-legged balance test has not been reported in children; however, the standard error of measurement (SEM) reported by De Kegel et al. (2011) was 10.16s with eyes open and 13.37s with eyes closed. Children with OWB may perform less well in SLS tests due to inadequate strength and muscular endurance to maintain standing on the leg and counter the increased torque required to stabilise a larger body mass. Furthermore, children with OWB's impaired balance may be due to limited sensory feedback under the feet (Section 1.3.2).

Table 1-9 Studies comparing single-leg stance performance in typical weight, overweight and obese children.

	Age (yrs)	n	SLS performance	Main findings
Pathare et al. (2013)	5-9	n=70	Single leg balance (s) OWB 8.3 ± 4.2 TW 14.0 ± 7.2	OWB significantly shorter balance time
Graf et al. (2004)	5-10	OB n = 20 OW n = 15 TW n = 213 UW n = 30	n times touched the ground 8.90 7.20 6.87 4.60	Significant differences between OB and UW, and TW and UW
Gray & Smith (2003)	5-18	n = 155	Time not reported	No significant correlation between BMI and balance time
Häcker at el. (2020)	6-12	OB n = 42 Severe OB n = 58	Single leg balance on bar (s) 19.4 ± 18.6 14.4 ± 14.9	No difference between groups
Merder-Coşkun et al. (2017)	6-15	OWB n = 103 TW n = 125	Single leg balance (s) 90.0 ± 105.5 140.0 ± 111.3	OWB significantly shorter time

Note: BMI = Body Mass Index, OB = obese, OW = Overweight, TW = Typical weight, UW = Underweight

1.3.4.3 Sit-to-stand test

The Sit-to-stand test (STS) may used to infer muscular strength (of the quadriceps), stability (in clinical populations), and exercise capacity (Bohannon & Crouch, 2019; Ng, 2010; Reychler et al., 2020). The STS requires participants to stand and sit down again (with hands across their chest) as many times as possible in one minute. In typically developing children, the STS has excellent (ICC 0.90) test-retest reliability (Reychler et al., 2019). In a comparison of TW, overweight, and obese youth separately (10 - 15 years), Nunez-Gaunaurd et al. (2013) found OWB groups to perform significantly fewer STS repetitions (overweight 26.5 ± 5.1, obese 23.1 ± 4.6) than TW children (27.25 ± 6.9). Obese children also take a significantly longer time to go from sitting to standing (3.89 ± 1.8 vs 1.59 ± 0.2 s) and take an average of 1.4 s to prepare to stand, whilst TW children take no preparation time (Riddiford-Harland et al., 2006). A slower STS transition suggests more time is required to generate adequate muscular force to rise from sitting in OWB (Cilli, Serbest, & Kayaoglu, 2021). Comparisons between OWB and TW children repeatedly show OWB are less able to produce as much lower limb power relative to body weight (Cowley et al., 2020). Additionally, obese children use their trunk in an exaggerated back and forward range of motion to generate adequate angular trunk momentum to stand, which may further increase postural stability demands. (Riddiford-Harland et al., 2006).

1.3.4.4 Six minute timed walk

The 6MTW measures how far an individual can walk at a self-selected speed along a marked walkway in six minutes, taking rest if and when required. Tests in children with obesity show that the 6MTW has good reliability (ICC 0.84; Morinder, 2009). Children with OWB typically walk a shorter distance during 6MTW tests compared to TW children; however, this difference is not consistent (Table 1-10). Pathare and Haskvitz (2012) reported no significant difference in 6MTW walk distance between TW children and children with OWB (Table 1-10). Differences in mean distances walked between studies may be due to the age of participants (distance walked increases with age) and the distance of the track. Of the studies comparing 6MTW in OWB and TW children, Morinder (2009) used a 70m track, Pathare and Haskvitz (2012) used an 18 and 20m track, and Tsiros et al. (2012) used a 10 m track; Nunez-Gaunaurd et al. (2013) did not state the track length. Longer track lengths require fewer turns and may result in a greater distance walked (American Thoracic Society, 2002). No other studies comparing 6MTW distance in children with OWB are available to compare across studies using the same track lengths.

Table 1-10 Studies comparing six minute-timed-walk performance in typical weight, overweight and obese children.

	Age (years)	n	6MTW (m)	Main findings
Morinder (2009)	8-16	TW n= 250 OB n=97	TW 662.6 ± 61.1 OB 571.2 ± 65.5	OB walked a significantly shorter distance
Nunez-Gaunaurd et al. (2013)	6-12	TW n= 48 OB n = 19	TW 597.53 ± 60.59 OB 552.28 ± 64.75	OB walked a significantly shorter distance
Tsiros et al. (2012)	10-13	TW n=132 OB n=107	TW 547.2 ± 6.8 OB 470.9 ± 5.3	OB walked a significantly shorter distance
Pathare and Haskvitz (2012)	5-9	TW n=41 OWB n=29	TW 525.4 ± 58.1 OWB 535.2 ± 63.6	No significant difference between groups

Note: 6MTW = six minute timed walk, OB = Obese, OWB = Overweight and obese, TW = Typical weight.

The average difference in 6MTW distance between OWB and TW groups (for those studies finding a significant difference) is 70.98 m. Morinder (2009) reported the smallest detectable change for 6MTW distance in obese children as 68 m. Interventions that result in increases in the walking distance close to that of TW children may show a significant improvement in the physical function of children with OWB. Whilst cardiovascular fitness has been theorised to be a limiting factor in OWN 6MTW performance, the correlation between 6MTW distance and relative VO^2max is weak (*r* =0.34; Morinder, 2009). Whilst, the weak correlation between 6MTW distance and relative VO^2max may be due to the homogeneity of VO^2max, differences in 6MTW performance may be due to walking inefficiency and biomechanical differences (Huang et al., 2013). Innate walking patterns and velocities are subconsciously selected by participants to be the most energetically efficient (Kuo, 2007). Therefore, given the larger mass, children with OWB may choose a slower walking speed to reduce the energetic cost of carrying a larger mass. However, children with OWB exhibit kinetic and kinematic gait patterns (such as increased step width to increase stability) indicative of a higher energy cost (Huang et al., 2013). Therefore, children with OWB may perform less well in 6MTW tests due to biomechanical inefficiencies.

1.3.4.5 Summary of Clinical Physical Function Measures

6MTW, TUG, SLS and STS are physical function tests that are cost and time-effective, easy to administer, and represent aerobic function, coordination, balance, and strength. Children with OWB tend to walk less distance in a 6MTW test, take longer in TUG tests, complete fewer repetitions in STS and are unable to maintain balance for as long in SLS tests compared to TW counterparts (Morinder, 2009; Nunez-Gaunaurd et al., 2013; Pathare & Haskvitz, 2012; Tsiros et al., 2012). Tsiros et al. (2020) suggested that physical function deficits in children with OWB are a product of the constraints of excess mass, MSK structural and functional maladaptation (e.g., altered gait biomechanics, joint misalignment, and altered skill acquisition), and lower levels of PA. These factors further increase excess mass and provide less opportunity to develop motor skills. Targeting physical function outcomes may help break this cycle of poor physical function, reduced PA, motor skills, and increasing OWB. Some gaps exist in the literature for reliability and change statistics for clinical physical function tests in children with OWB. Whilst data exists for the reliability of these measures in TW children, it is important to establish reliability within the OWB population and determine the error for each measure to understand the thresholds for changes in performance from interventions.

Clinical measures of physical function closely resemble activities of daily life and are linked with health status and HRQoL (Beaudart et al., 2019). Children with OWB typically perform worse in physical function tests as movements require control of body mass against gravity (Chivers et al., 2013; D'Hondt et al., 2009). The assessment of physical function and the development of strategies to tackle functional deficits in children with OWB are needed. However, performance measures may not fully explore the associations between poor function, pain, and MSK malalignment and disorders. A biomechanical analysis of movement patterns and joint loads during daily living provides greater detail.

1.3.5 Gait

Walking is a daily physical function that is a recommended modality for the prevention and treatment of OWB (World Health Organization, 2016). Walking demands adequate postural stability and muscular strength to lift and propel the centre of mass forward. During the phases of walking, ground reaction forces act on the body in vertical, anterior-posterior and mediolateral directions and place complex demands on the lower limb musculature, structures, and postural stability system to maintain support and forward progression (Figure 1-8). Gait biomechanics in children are affected by OWB, which may increase the risk of pain, malalignment, and maladaptation, particularly on the developing MSK system, and impact walking proficiency (Molina-Garcia et al., 2019; Tsiros et al., 2020).

1.3.5.1 Principles of Gait

Walking is a cyclical motion that requires the coordination of many systems in the body to support and accelerate the CoM upward and forward while simultaneously controlling external forces acting on the body. Figure 1-8 illustrates the systems and forces acting within and on the body during gait. Simplified models demonstrate how this series of complex systems results in the fundamental principles of human locomotion. Kuo (2007) proposed the theory of 'principles of dynamic walking' to explain the fundamental principles of human locomotion. Kuo's model of gait combines the mainly passive stance phase principles of the double pendulum theory with the transfer of energy around heel contact and push-off (Figure 1-9). A safe and efficient step-to-step transition requires interlimb coordination and balance; push-off requires muscular coordination and power; and the collision event (foot strike) requires power absorption and transfer through passive structures and muscle synergies. Gait is a cyclical motion described in events of a single gait cycle (initial contact to heel contact of the same leg) and has two main phases: stance phase (foot in contact with the ground) and swing phase (leg swinging forward and placement in front of the body). The stance phase and swing phase can be broken down to further identify key events and phases in the gait cycle, as shown in Figure 1-10, and will be used throughout the thesis to describe motion during the gait cycle.

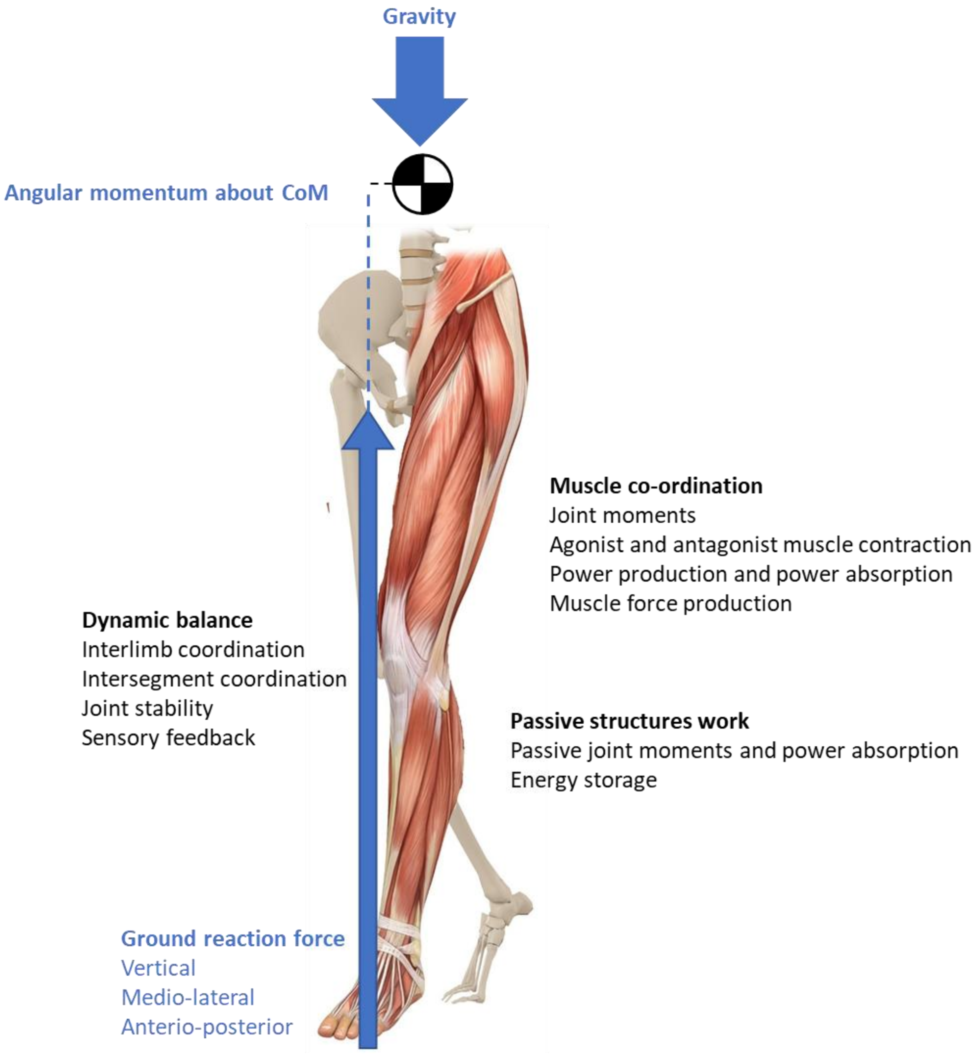

Figure 1-8 Schematic of the forces acting on the centre of mass (blue) and the forces and systems acting within the body to maintain support, balance and forward progression during walking.

From around the age of one year, children walk independently, but their competency level continues to develop until around 7 years old when competency and pattern reach approximate adult values (Sutherland et al., 1988). Gait velocity also increases with age (~64cm/s at 1 yrs, ~114cm/s at 7 yrs) and increased step length as growth results in greater leg length (Sutherland et al., 1988). The stance phase of gait gets shorter during growth and maturation as children become better able to balance and stabilise the CoM through dynamic movement (Sutherland et al., 1988). Shumway-Cook and Woollacott (1985) suggested that between the ages of 4 and 6 years, children go through the largest transition in the development of postural stability as children begin to use a combination of visual input and proprioceptive feedback from joints and muscular synergies. At each event and within each phase of gait, a series of muscle and joint actions occur to control and progress movement. The following section discusses some of the key actions during these phases relative to postural stability and muscle strength in children with OWB.

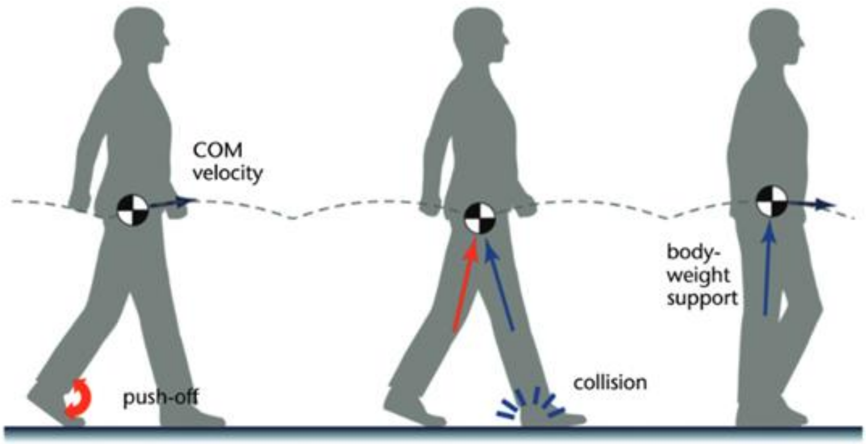

Figure 1-9 Principals of dynamic walking (Kuo, 2010).

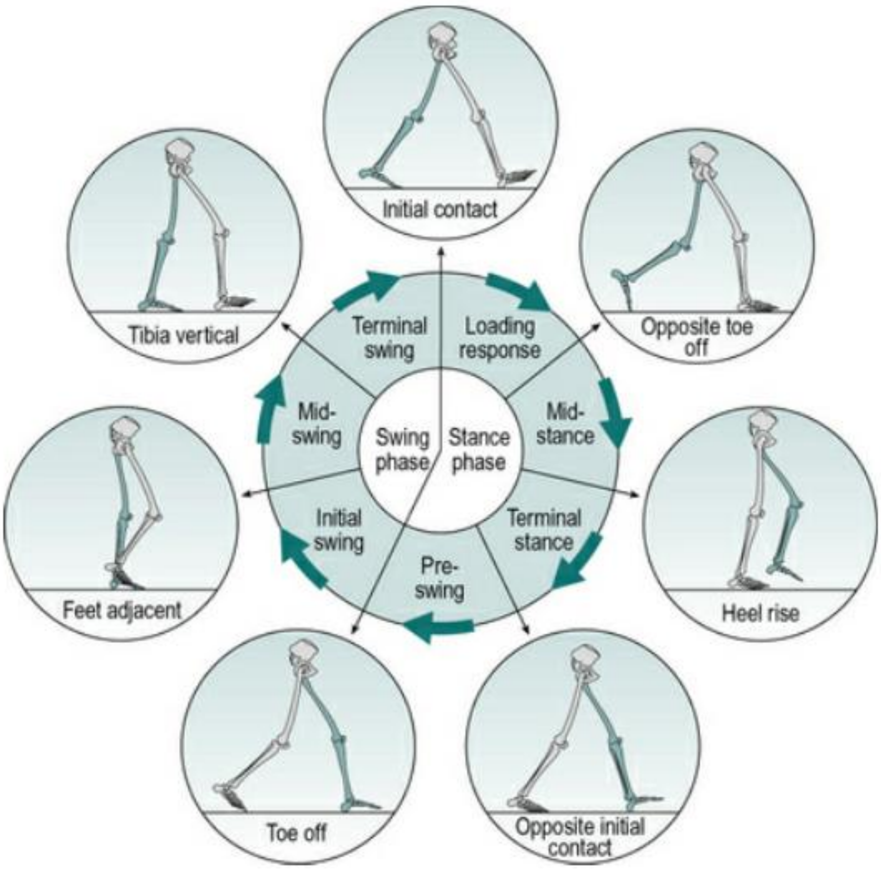

Figure 1-10 Gait cycle events and main gait phases (Levine et al., 2012).

1.3.5.2 Gait findings in overweight and obese children

During each gait phase and transition, a series of coordinated joint and muscle actions occur to control and propel the body forward. Figures 1-11 to 1-17 describe the action of muscle groups, joint rotations and movement of ground reaction force during the stance phase of gait, which requires the limb to take the weight of the body, move the CoM over the limb, prepare for the contralateral limb to make contact, and push off into the swing phase. The following sections describe and review lower limb gait mechanics with a particular focus on postural stability and muscular strength deficits and how this may relate to gait differences found in OWB compared to TW children.

Gait differences between OWB and TW children are well-documented and are detailed across gait phases and joints in Figures 1-18 to 1-26. OWB significantly influences gait function, which may further impact MSK health. Altered temporal-spatial measures in children with OWB are frequently reported (Table 1-11) as a mechanism to reduce the muscular demand required to move a heavier body (D'Hondt et al., 2010; Deforche et al., 2009; Huang et al., 2013; Hills & Parker, 1991; Hung et al., 2012). Slower walk speeds decrease lower limb load and muscular effort, which helps manage both relative lower limb weakness and postural stability challenges of larger body mass (Rutherford & Hubley-Kozey, 2009). Faster walking speeds demand greater muscle force for propulsion, making slower gait energetically favourable for children with OWB.

OWB children demonstrate higher joint moments and powers (Figures 1-18 and 1-21) in absolute terms, attributed to the need to control and propel a larger mass (Mahaffey et al., 2018; Shultz et al., 2014; Shultz et al., 2009; Shultz et al., 2010). However, these differences often disappear when normalised to body weight, indicating that increased demands arise primarily from the larger mass rather than biomechanical inefficiencies (Shultz et al., 2009; Shultz et al., 2010; Nantel et al., 2006). The increased plantarflexion moment and power seen in OWB compared to TW children particularly during loading and push-off (Figures 1-20) are associated with greater vertical GRF and higher plantar pressures under the foot, potentially elevating the risk of MSK loading and overuse injuries (Gushue et al., 2008; Shultz et al., 2009; Shultz et al., 2010; Shultz et al., 2014).

1.3.5.2.1 Overweight and obese gait mechanics associated with postural stability

Studies reporting significant differences in walking velocity (Table 1-11) find children with OWB tend to walk slower than TW peers (D'Hondt, Deforche, De Bourdeaudhuij, et al., 2011; Nantel et al., 2006; Orantes-Gonzalez & Heredia-Jimenez, 2021; Rubinstein et al., 2017; Vignolo et al., 1988). The slower speeds, coupled with shorter stride lengths relative to height, indicate a more tentative gait aimed at compensating for reduced stability in children with OWB, allowing more time for dynamic postural stability during transitions between stance and swing phases (Browning, 2012). Children with OWB spend more time in double support, which allows additional time for deceleration and acceleration of their larger body mass (Molina-Garcia et al., 2019).

A wider step width, consistently observed in children with OWB (Deforche et al., 2009; Huang et al., 2013; Hung & Gill, 2013) is suggested to be a mechanism to increase the base of support and aid stability (Browning, 2012). However, it has also been suggested that OWB walk with wider steps due to adipose tissue increasing thigh girth (Huang et al., 2013; Westlake et al., 2013). Increased out-toeing, also thought to be a strategy to increase the base of support, may also shift the vertical GRF closer to the knee joint centre, potentially reducing knee joint load as a compensatory strategy (Chang et al., 2007).

After the loading phase, when the opposite limb leaves the ground, demands on stability are increased as the body transitions to single-limb support (Figure 1-13 to 1-16). Stability in the frontal plane, is maintained primarily through hip abductor power absorption and generation. Weakness in the hip abductors can compromise these mechanics, affecting overall gait stability. Greater hip abduction power generation during loading response and midstance seen in children with OWB (Figure 1-21) illustrates this strategy aimed at improving stability while walking at self-selected speeds (Shultz et al., 2014. Reduced hip extension during mid-stance seen in children with OWB (Figure 1-18) is associated with shorter stride lengths and is suggested to improve energy efficiency while maintaining stability (Blakemore et al., 2013). During stance, TW children tend to remain in a neutral or slightly adducted knee position, and children with OWB exhibit a significantly larger range of motion and greater abduction, resulting in a valgus position through stance (McMillan et al., 2009, 2010). The increased frontal plane motion has been linked with a greater incidence of osteoarthritis (OA) in adults (Hunt et al., 2006). Shultz et al. (2014) reported less maximal internal rotation and more maximal external rotation in obese children but no significant difference in total range of motion between OWB and TW groups. OWB exhibit a greater range of motion and loading through the knee in the frontal and transverse planes (Figure 1-22 and 1-25), which are linked with strategies to increase stability and altered foot motion.

Mahaffey et al. (2016) found FM% to significantly predict midfoot eversion and dorsiflexion, as well as calcaneus abduction and plantarflexion. Moreover, in multiple regression models, including BF and temporal-spatial measures, stance phase duration and step distance were significantly associated with calcaneus plantarflexion and midfoot eversion, respectively which is linked to the lowering of the medial longitudinal arch seen in *pes planus* (Kim & Weinstein, 2000). The greater calcaneus abduction position in children with OWB compared to TW children supports studies reporting an “out-toeing” to encourage a wider base of support (Hills & Parker, 1991). The adverse alignment and resultant increased loads through the knee joint may increase the risk of pain and future OA if not altered (Hunt et al., 2006). Children OWB exhibit reduced plantar flexion at toe-off, likely to minimise propulsive forces and reduce balance perturbations during push-off (D’Hondt et al., 2011). Changes in push-off mechanics, such as increased reliance on hip flexors instead of ankle plantar flexors, suggest mechanisms to maintain stability during gait (Mahaffey et al., 2018; McMillan et al., 2010). The combined ankle and hip strategies to maintain stability on OWB gait may not be fully captured by CoP measures alone (as discussed in Section 1.3.2.4).

1.3.5.2.2 Overweight and obese gait mechanics associated with muscular strength

Muscle strength deficits in the hip abductors and plantar flexors significantly impact gait mechanics, particularly during weight acceptance and single-limb support phases (van der Krogt et al., 2012). The hip abductors play a critical role in controlling hip adduction and pelvic drop, with large deficits in strength potentially leading to greater pelvic drop and compromised gait stability (Rutherford & Hubley-Kozey, 2009). Children with OWB demonstrate higher absolute hip abduction moments during stance, though these differences often disappear after body weight normalization (Shultz et al., 2009; Lerner et al., 2016). McMillan et al. (2010) found lower relative hip abduction moments in OWB, possibly reflecting muscle weakness during early stance as the limb accepts weight. However, discrepancies across studies may arise from methodological differences, such as using skin markers or estimating the hip joint centre location based on anatomical measurements (Kainz et al., 2015). Frontal plane hip kinematics in children with OWB are characterised by greater total displacement, larger frontal plane moments during early stance, and increased internal abduction moments throughout. These dynamics likely represent compensatory adaptations to manage chronic loading from excess body mass, as greater hip external rotation moments reported in children with OWB also become non-significant after body weight normalization (Shultz et al., 2014).

Relative weakness in the plantar flexors is particularly impactful during late stance, where these muscles generate nearly all the support required for push-off (Anderson & Pandy, 2003). Reduced plantarflexion in OWB may stem from relative weakness in the plantar flexors, with Gushue et al. (2005) and Shultz et al. (2009) reporting lower peak plantarflexion moments in OWB (Figure 1-20). Children OWB demonstrate reduced plantar flexion moments, even after normalisation to body weight and height, suggesting inadequate strength relative to body mass (Gushue et al., 2005; Shultz et al., 2009). However, it should be noted that plantarflexion peaks are typically lower at slower walking speeds (commonly seen in children with OWB; Van Der Linden et al., 2002). The reduction in plantar flexion moments, coupled with slower walking speeds, supports the idea that children with OWB adopt a cautious gait strategy to manage stability and reduce joint loads (van der Linden et al., 2002).

Both Gushue et al. (2005) and Lerner et al. (2014) found OWB groups to have significantly lower knee peak flexion moments during stance compared to TW children (Figure 1-19). Lerner found that OWB had lower knee flexion peak at faster walking speeds (1.5 m/s). However, there was no significant difference between OWB and TW groups at a slower speed (1.25m/s). Gushue et al. (2005) found OWB to have a lower knee flexion peak after normalising to walking velocity, indicating that children with OWB may employ altered sagittal knee kinematics as a strategy to reduce joint loads. Shultz et al. (2009) found OWB to have significantly greater peak knee flexion and extension moments than TW children. However, there was no difference between OWB and TW groups after accounting for body weight (Shultz et al., 2009). Similarly, Lerner and Browning (2016) found no significant difference between OWB and TW groups for peak sagittal plane knee moment relative to body weight. Gushue et al. (2005) reported no significant difference between OWB and TW groups in either absolute or body weight normalised sagittal knee moments. Additionally, Mahaffey et al. (2018) reported no significant relationships between FM% and sagittal knee moments. OWB may adopt a strategy to reduce joint loads due to inadequate strength relative to body mass (Theis et al., 2019). Singh et al. (2016) found that strength in children with OWB predicted greater knee extension peaks during self-selected speed walking, suggesting those who were stronger adopted a sagittal knee angle closer to that of TW peers which increases joint moment peaks.

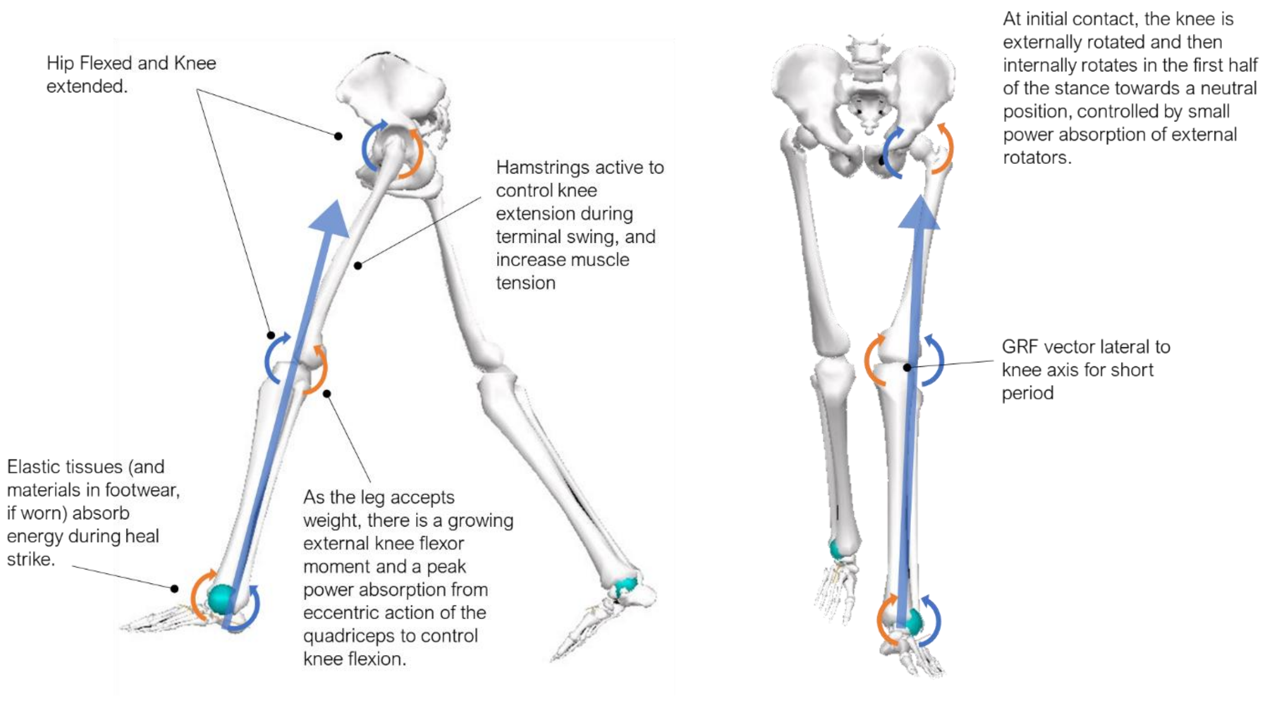

Figure 1-11 Ground reaction force (vertical blue arrow), external joint moment (curved blue arrow), internal joint moment (curved orange arrow) and centre of mass during Initial contact.

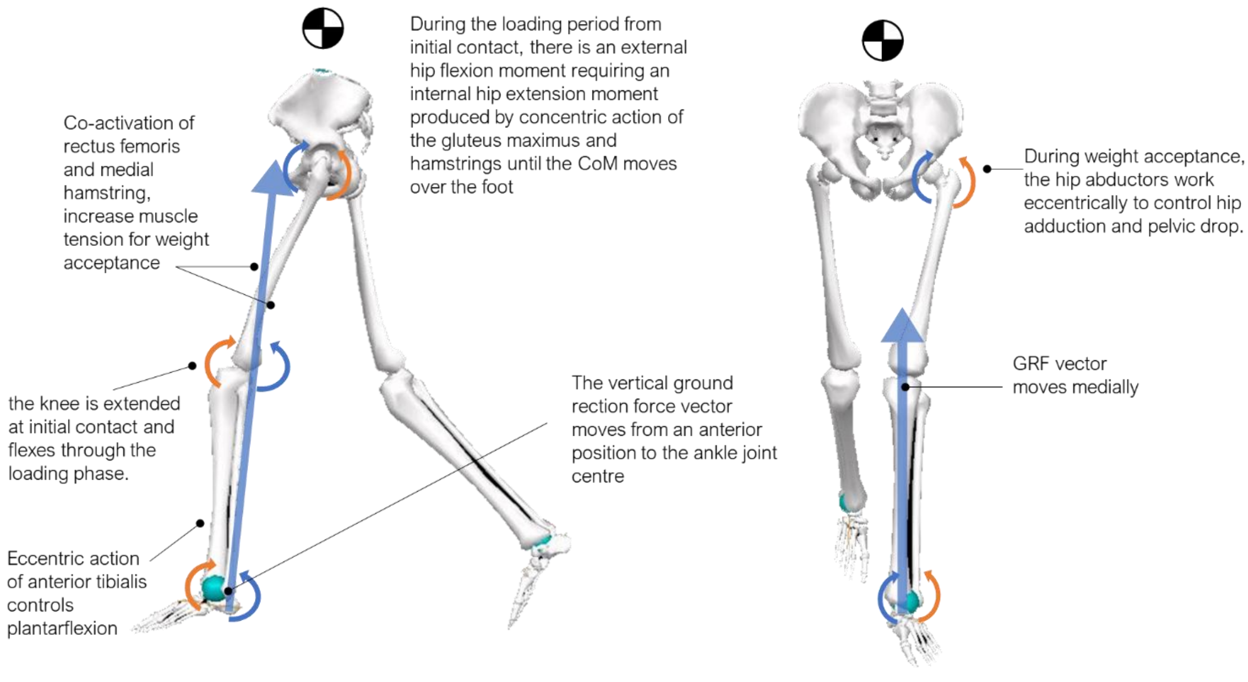

Figure 1-12 Ground reaction force (vertical blue arrow), external joint moment (curved blue arrow), internal joint moment (curved orange arrow) and centre of mass during the loading response.

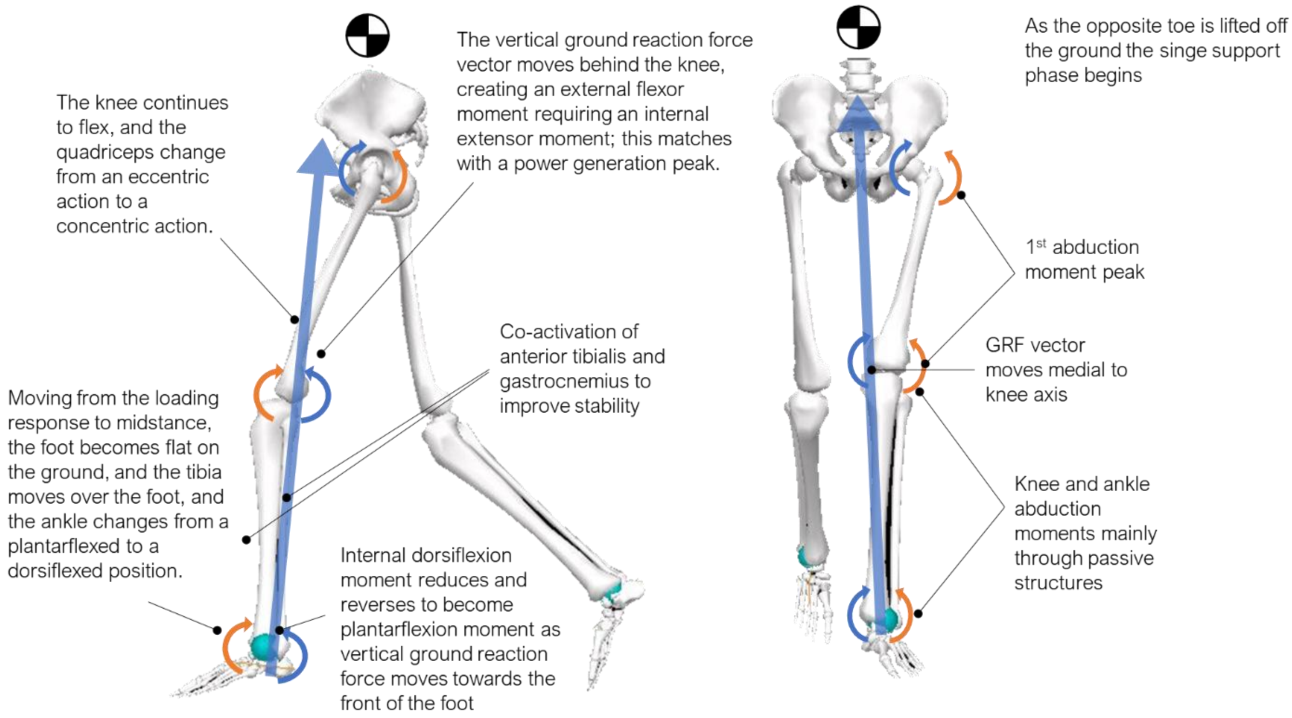

Figure 1-13 Ground reaction force (vertical blue arrow), external joint moment (curved blue arrow), internal joint moment (curved orange arrow) and centre of mass during opposite toe off.

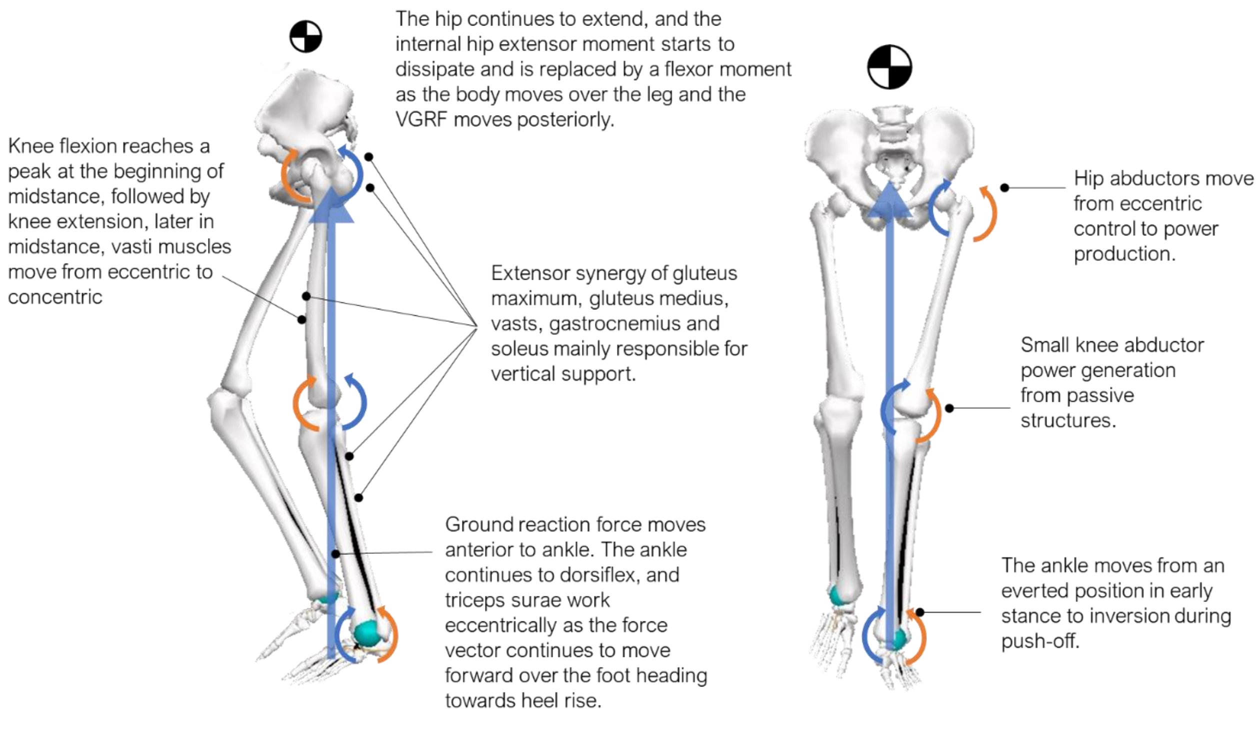

Figure 1-14 Ground reaction force (vertical blue arrow), external joint moment (curved blue arrow), internal joint moment (curved orange arrow) and centre of mass during midstance.

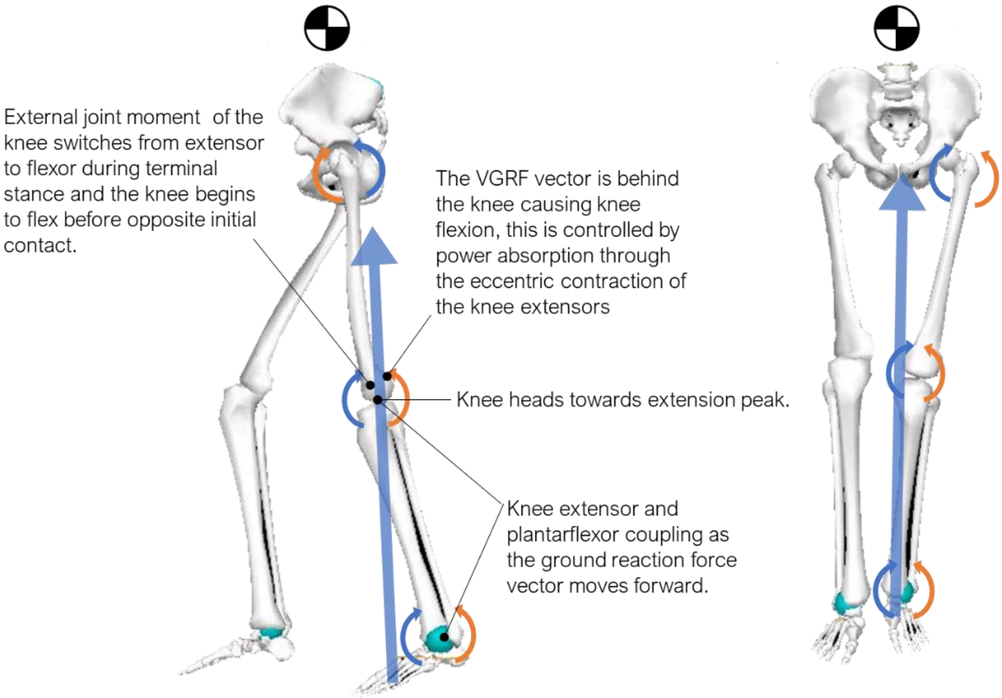

Figure 1-15 Ground reaction force (vertical blue arrow), external joint moment (curved blue arrow), internal joint moment (curved orange arrow) and centre of mass during heel rise.

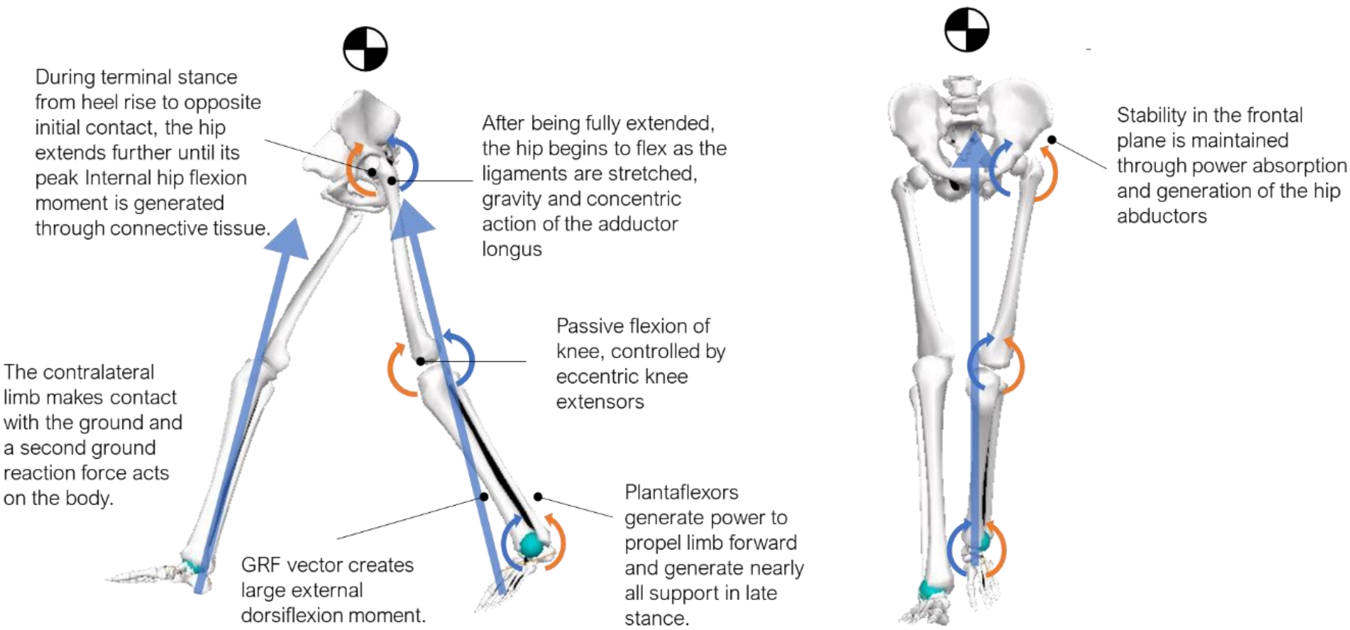

Figure 1-16 Ground reaction force (vertical blue arrow), external joint moment (curved blue arrow), internal joint moment (curved orange arrow) and centre of mass during terminal stance.

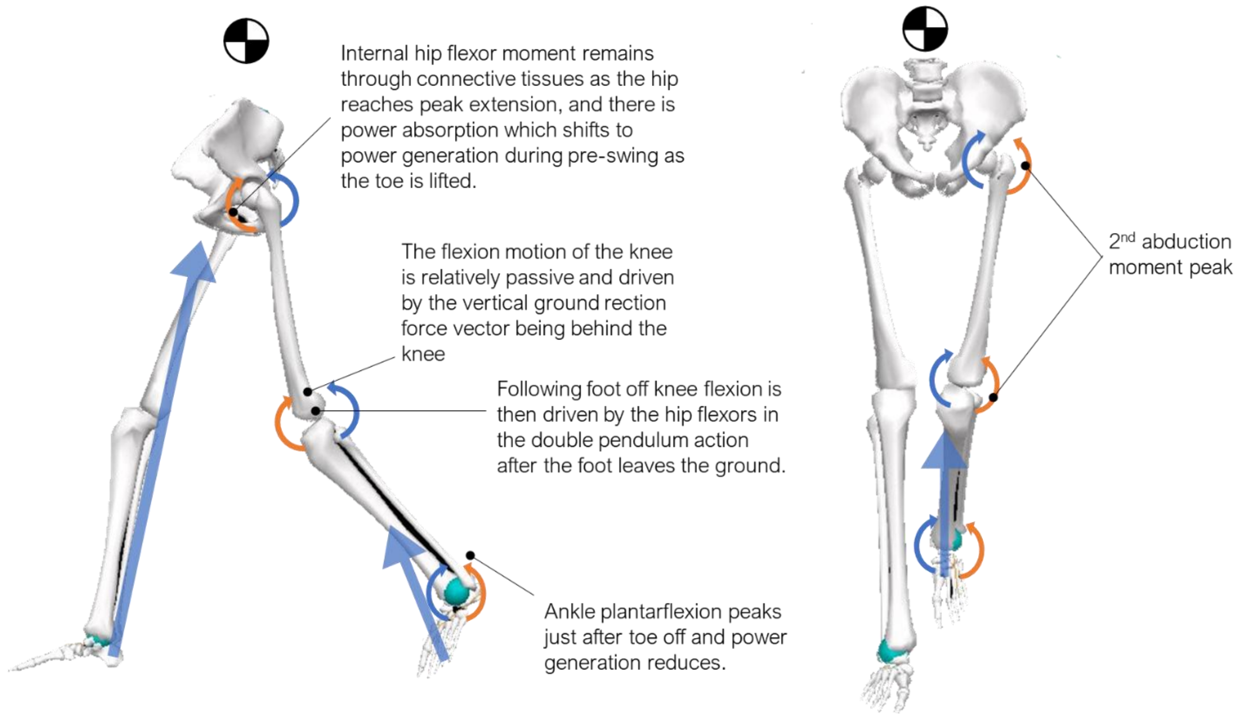

Figure 1-17 Ground reaction force (vertical blue arrow), external joint moment (curved blue arrow), internal joint moment (curved orange arrow) and centre of mass during toe off.

Table 1-11. Comparison between overweight and obese and typical weight children's temporal-spatial gait variables.

Study	Walking Speed	n	Gait Speed	Stride Length	Step Width	Stance Phase	Double Support Phase	Swing Phase	Single Support Phase
DHondt et al., 2010	Self-selected pace	OWB n = 16	0.80 ± 0.09 height/s	1.17 ± 0.09 cm	10.91 ± 1.98 cm *	60.67 ± 1.12 %GC	0.21 ± 0.03 s	39.33 ± 1.12 %GC	-
		TW n = 16	0.85 ± 0.08 height/s	1.20 ± 0.15 cm	8.11 ± 1.42 cm	61.04 ± 1.09 %GC	0.21 ± 0.02 s	38.96 ± 1.09 %GC	
Deforche et al., 2009	Walked as fast as possible	OWB n = 25	52.0 ± 20.3 cm/s	43.6 ± 7.1 cm	22.1 ± 3.0 cm *	-	-	-	-
		TW n = 32	49.6 ± 10.7 cm/s	42.6 ± 7.8 cm	19.5 ± 3.4 cm				
Huang et al., 2013	Self-selected pace	OWB n = 16	1.10 ± 0.08 m/s *	0.77 ± 0.05 m/height *	0.18 ± 0.05 cm *	60.65 ± 1.29 %GC *	20.97 ± 2.52 %GC *	-	39.67 ± 1.26 %GC *
		TW n = 16	1.25 ± 0.11 m/s	0.77 ± 0.08 m/height	0.14 ± 0.03 cm	58.07 ± 1.83 %GC	16.03 ± 3.65 %GC		41.83 ± 2.10 %GC
Hills & Parker, 1991	Normal walking speed	OW n = 10	0.90 ± 0.17 height/s *	-	-	-	-	-	-
		TW n = 4	1.03 ± 0.02 height/s						
McGraw et al., 2000	Self-selected pace	OWB n = 10	-	-	-	OWB Greater %GC	OWB Greater %GC	OWB Less %GC	-
		TW n = 10							
Nantel et al., 2006	Self-selected pace	OWB n = 10	1.01 ± 0.16 m/s	1.08 ± 0.16 m	-	62.7 ± 2.5 %GC	26.0 ± 5.5 %GC	-	36.6 ± 3.6 %GC *
		TW n = 10	0.98 ± 0.22 m/s	1.06 ± 0.20 m		62.3 ± 1.4 %GC	22.8 ± 3.0 %GC		39.5 ± 2.0 %GC
Hung et al., 2013	Self-selected pace	OWB n = 12	0.84 ± 0.12 m/s *	0.84 ± 0.07 cm/cm *	0.09 ± 0.02 cm/cm	55.4 ± 5.6 %GC	-	-	-
		TW n = 12	0.90 ± 0.12 m/s	0.88 ± 0.08 cm/cm	0.08 ± 0.03 cm/cm	52.7 ± 6.8 %GC			
Huang et al., 2013 (2)	Self-selected pace	OWB n = 8	Obese slower *	-	-	-	-	-	-
		TW n = 18							

Note: OWB = Overweight and obese, TW= Typical Weight, GC% = % of total gait cycle time. * denotes significant difference between groups.

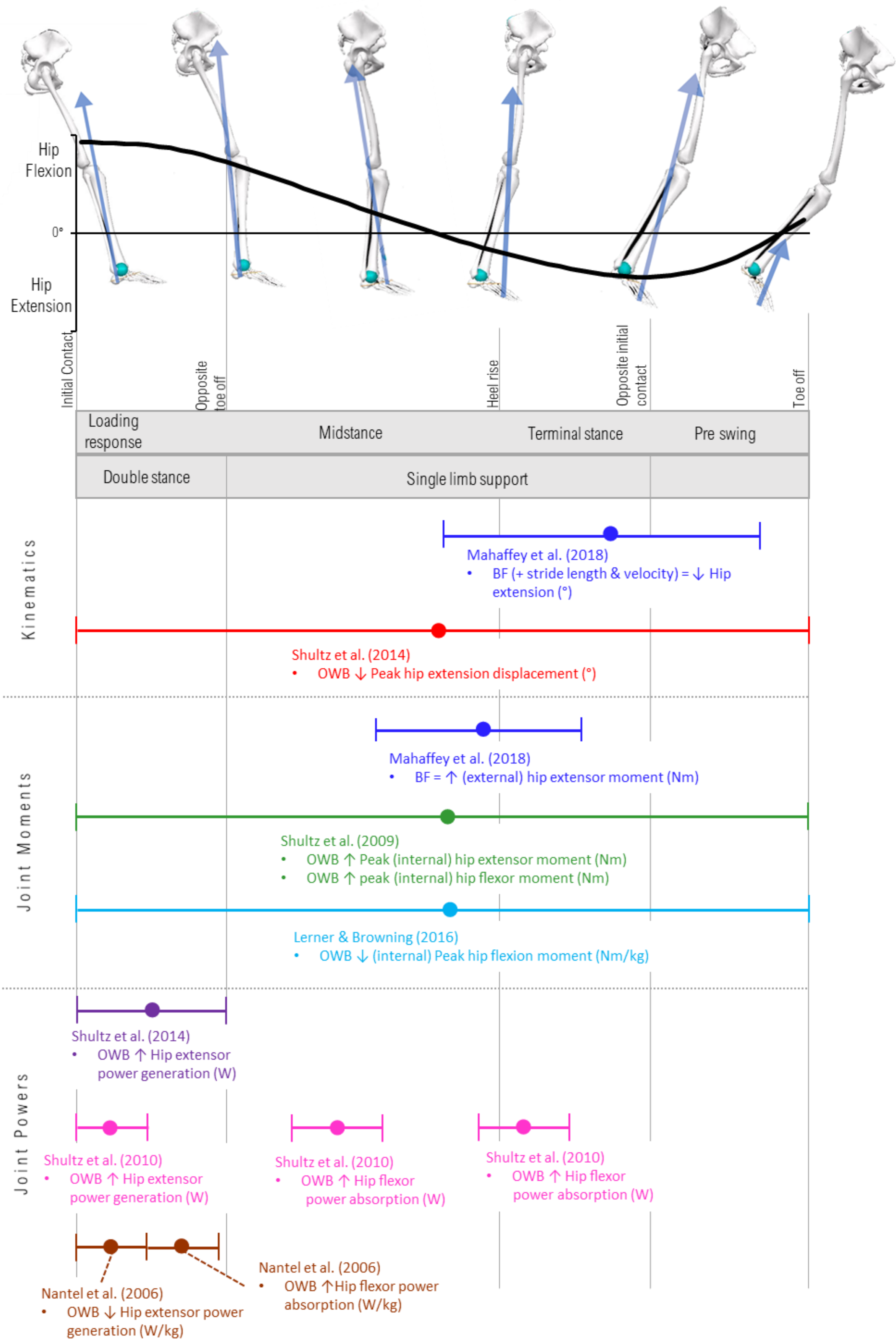

Figure 1-18 Statistically significant differences between overweight and obese and typical weight groups or relationships to body fat reported in children for the hip in the sagittal plane during stance.

Note: OWB ↓ = overweight obese children reduced, OWB ↑ = overweight and obese children greater, BF= relationship with body fat.

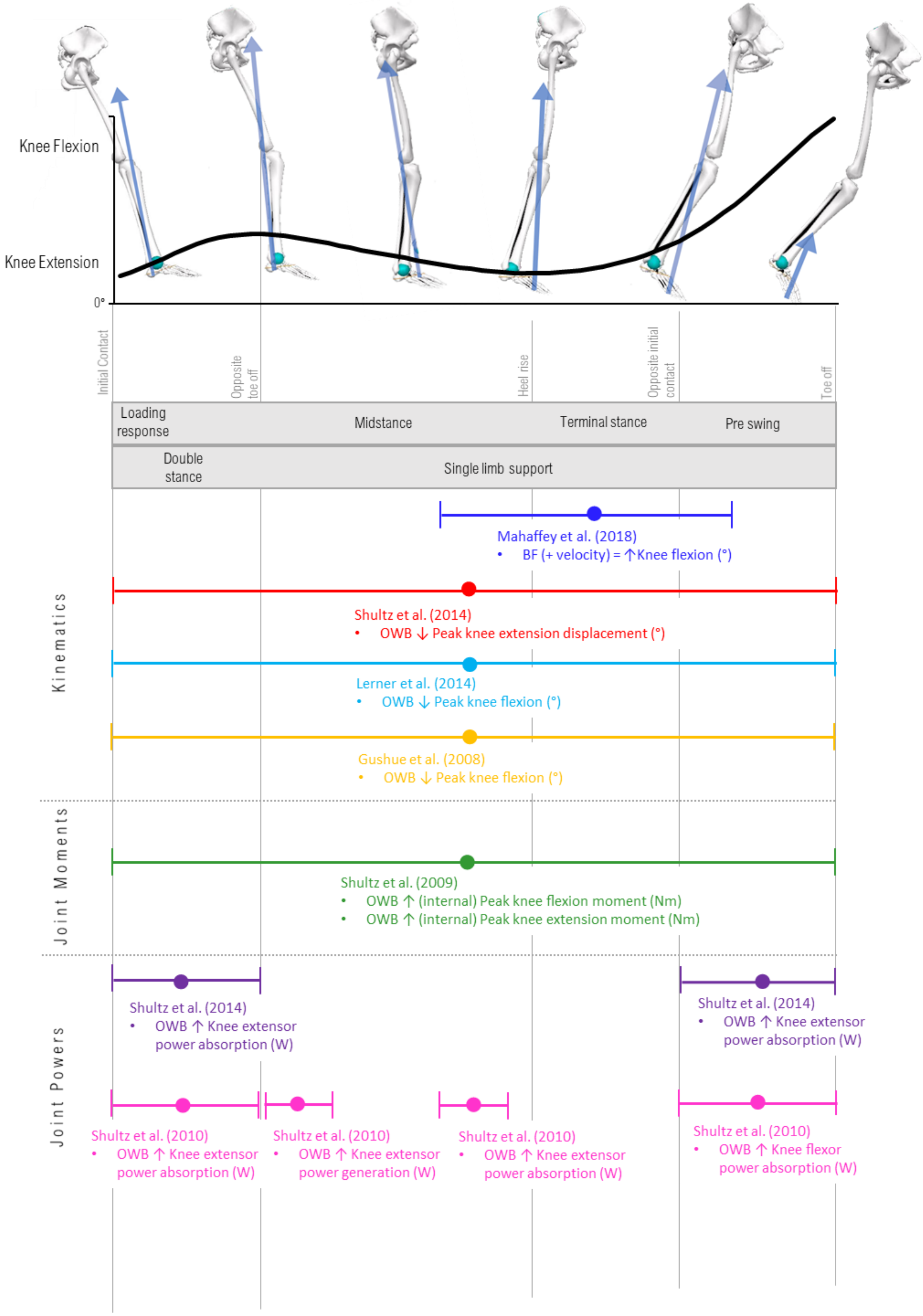

Figure 1-19 Statistically significant differences between overweight and obese and typical weight groups or relationships to body fat reported in children for the knee in the sagittal plane during stance phase.

Note: OWB ↓ = overweight obese children reduced, OWB ↑ = overweight and obese children greater, BF= relationship with body fat.

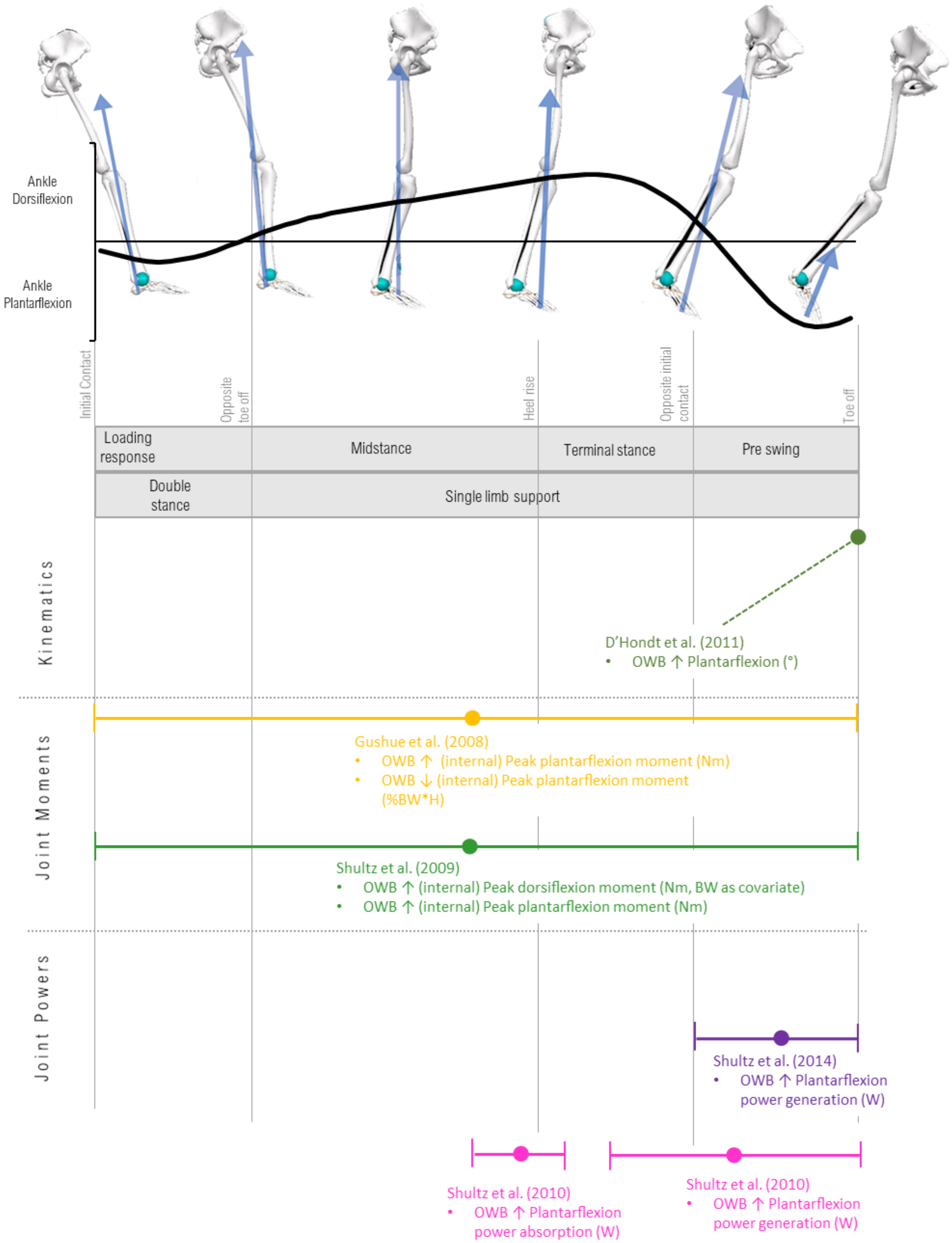

Figure 1-20 Statistically significant differences between overweight and obese and typical weight groups or relationships to body fat reported in children for the ankle in the sagittal plane during stance phase.

Note: OWB ↓ = overweight obese children reduced, OWB ↑ = overweight and obese children greater, BF= relationship with body fat.

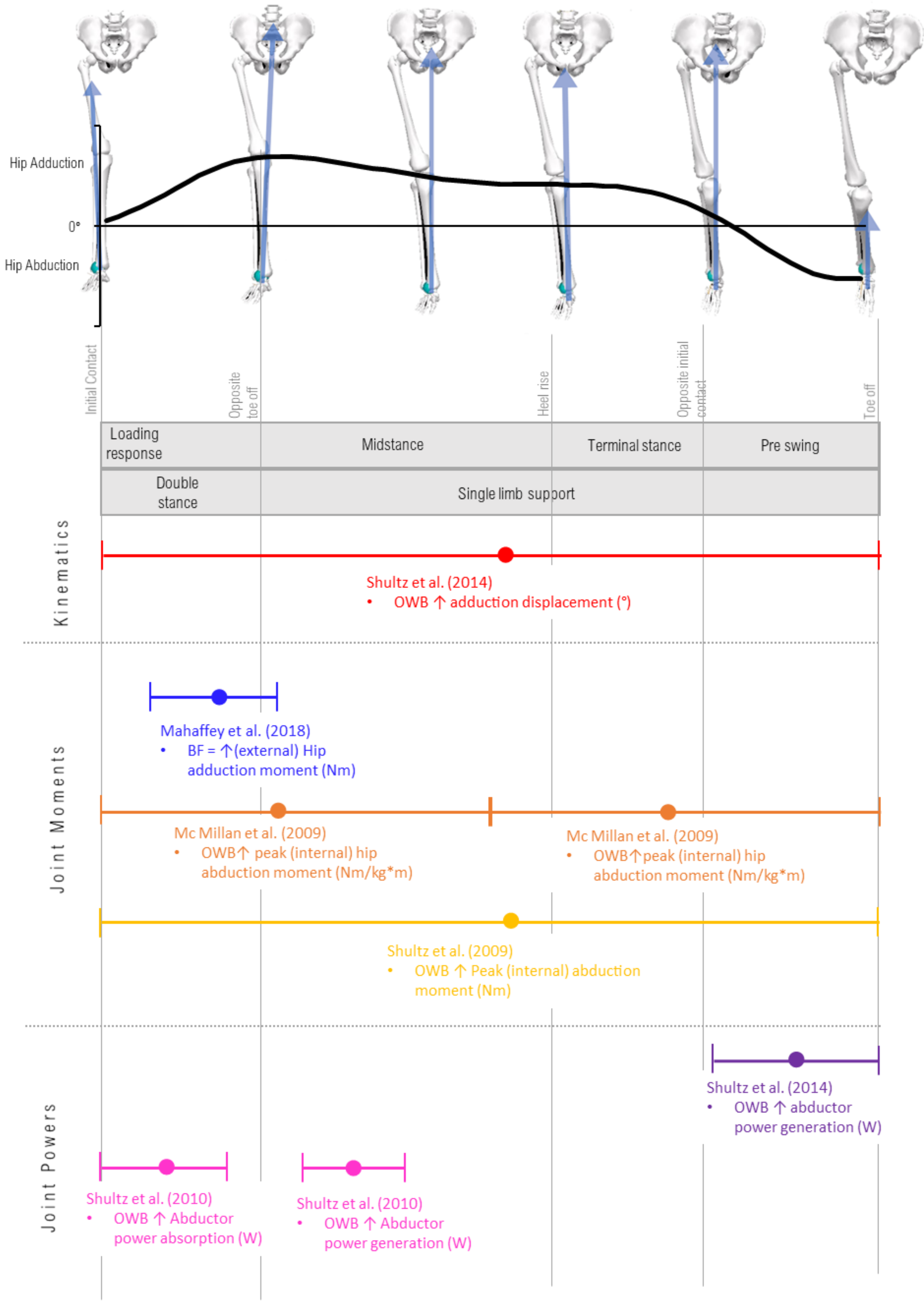

Figure 1-21 Statistically significant differences between overweight and obese and typical weight groups or relationships to body fat reported in children for the hip in the frontal plane during stance phase.

Note: OWB ↓ = overweight obese children reduced, OWB ↑ = overweight and obese children greater, BF= relationship with body fat.

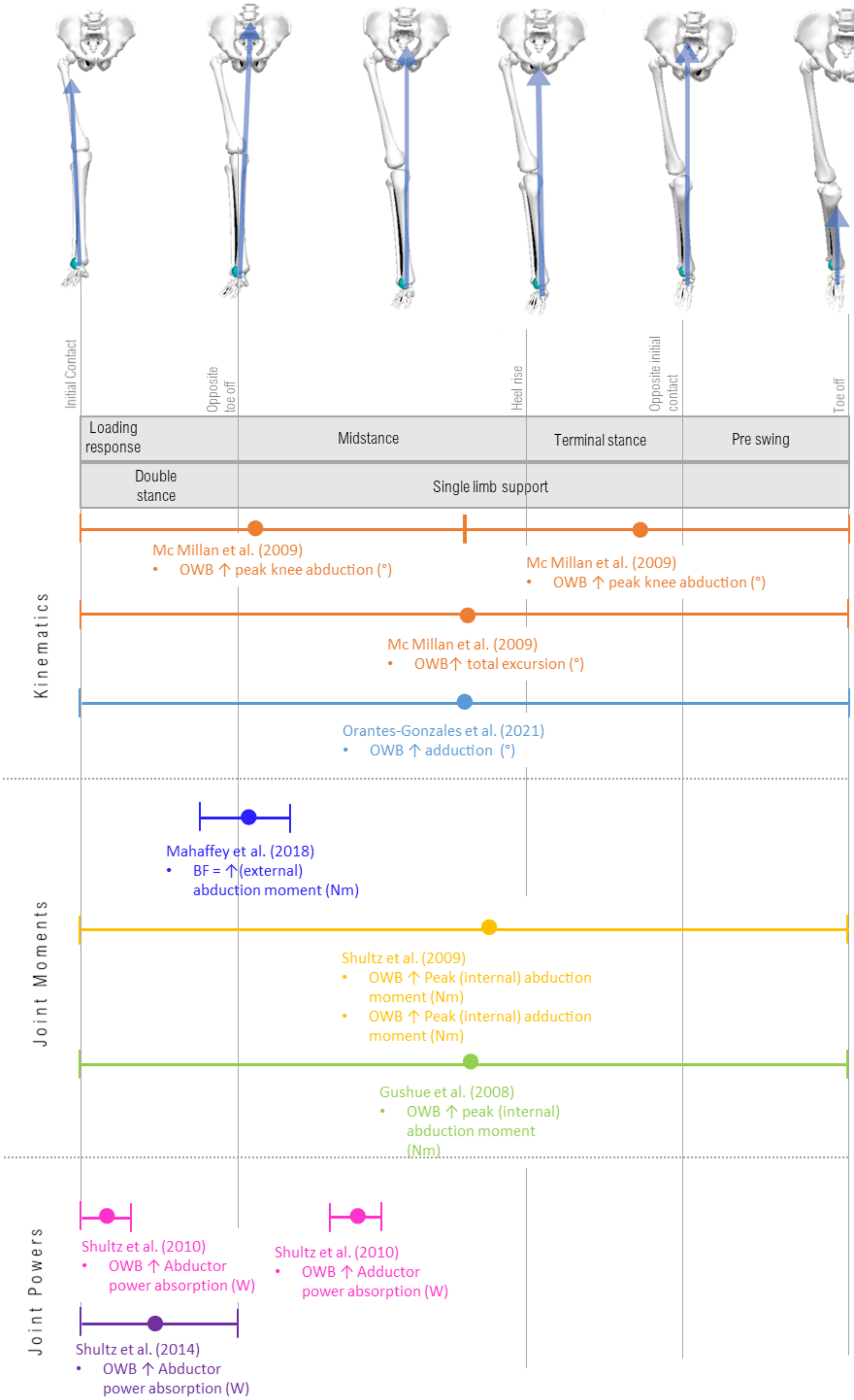

Figure 1-22 Statistically significant differences between overweight and obese and typical weight groups or relationships to body fat reported in children for the knee in the frontal plane during stance phase.

Note: OWB ↓ = overweight obese children reduced, OWB ↑ = overweight and obese children greater, BF= relationship with body fat.

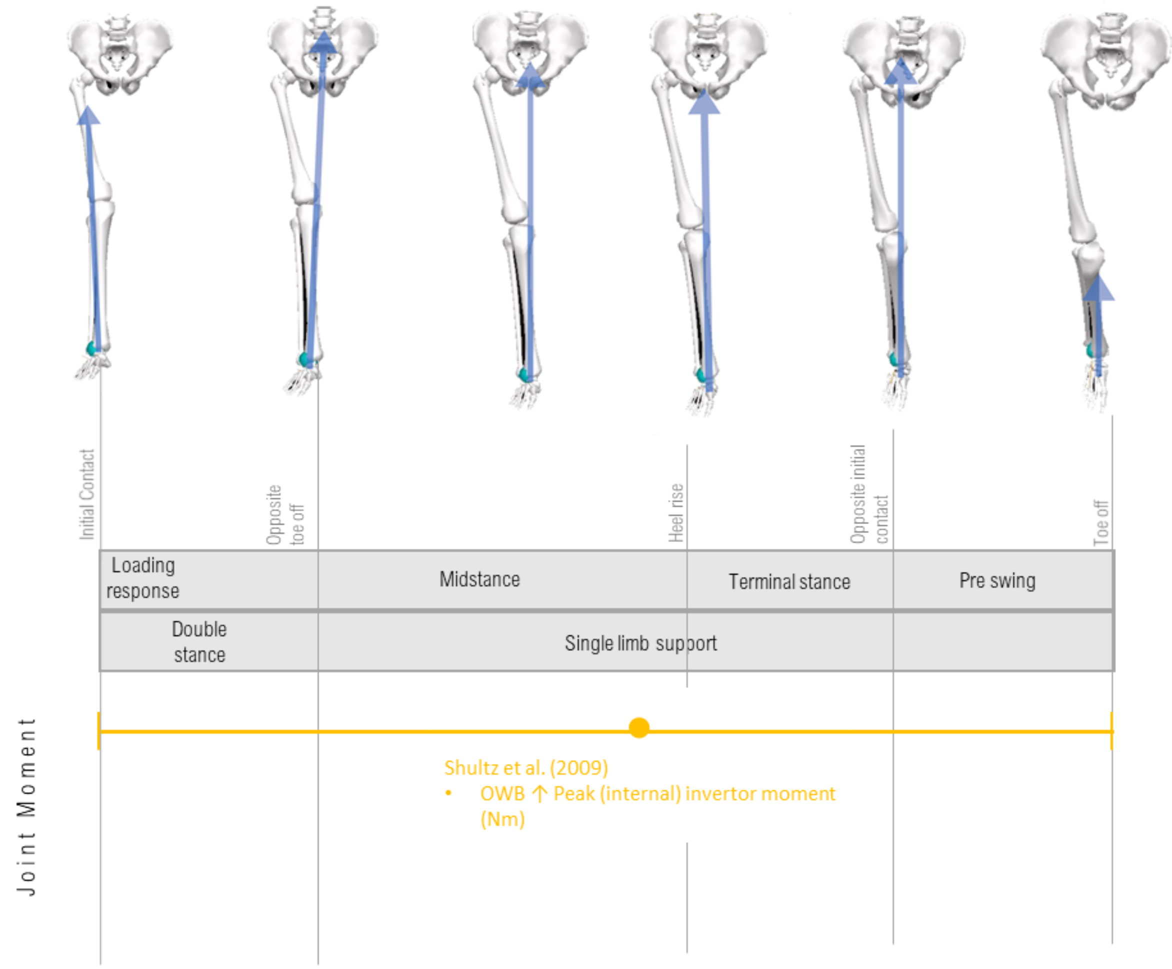

Figure 1-23 Statistically significant differences between overweight and obese and typical weight groups or relationships to body fat reported in children for the ankle in the frontal plane during stance.

Note: OWB ↓ = overweight obese children reduced, OWB ↑ = overweight and obese children greater, BF= relationship with body fat.

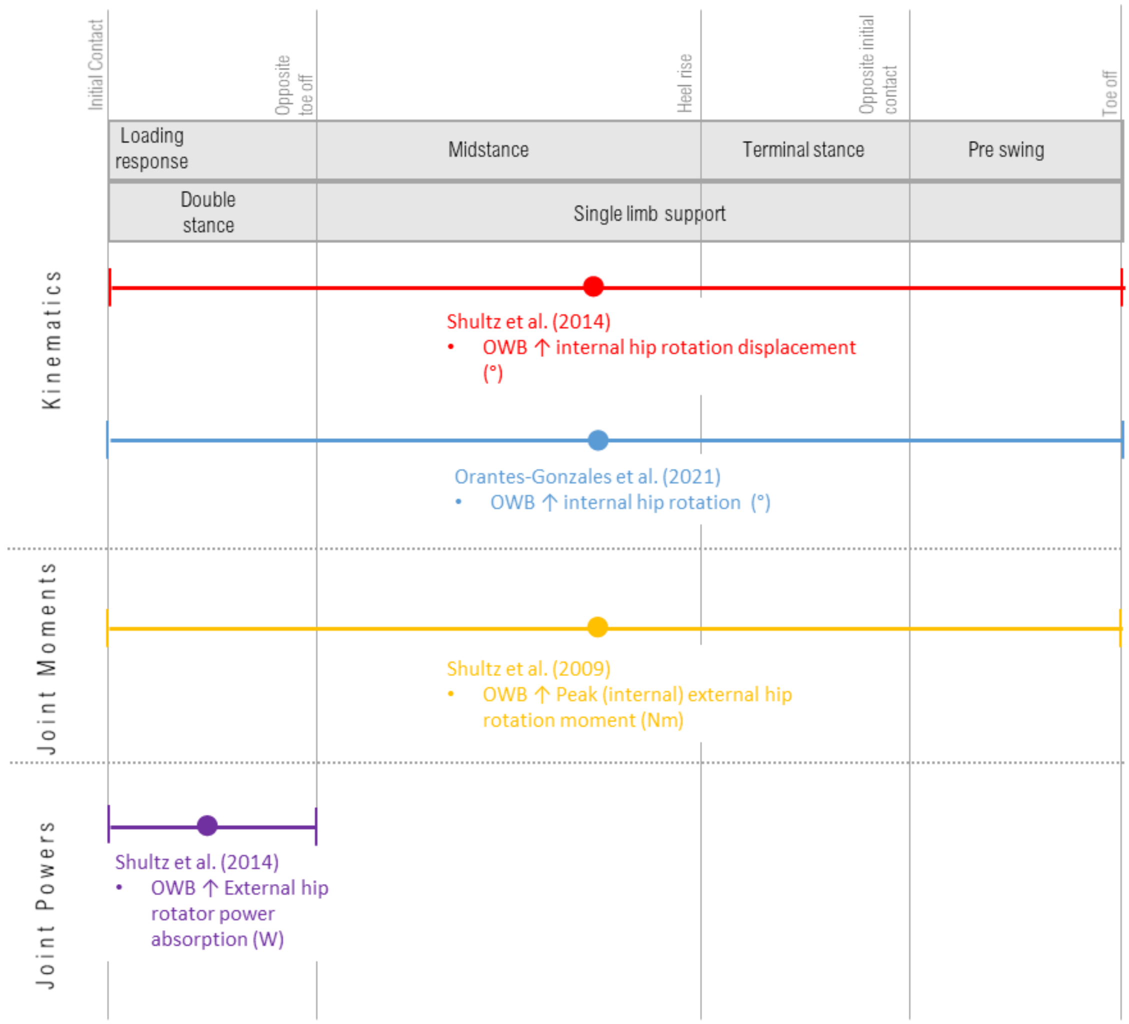

Figure 1-24 Statistically significant differences between overweight and obese and typical weight groups or relationships to body fat reported in children for the hip in the transverse plane during stance phase.

Note: OWB ↓ = overweight obese children reduced, OWB ↑ = overweight and obese children greater, BF= relationship with body fat.

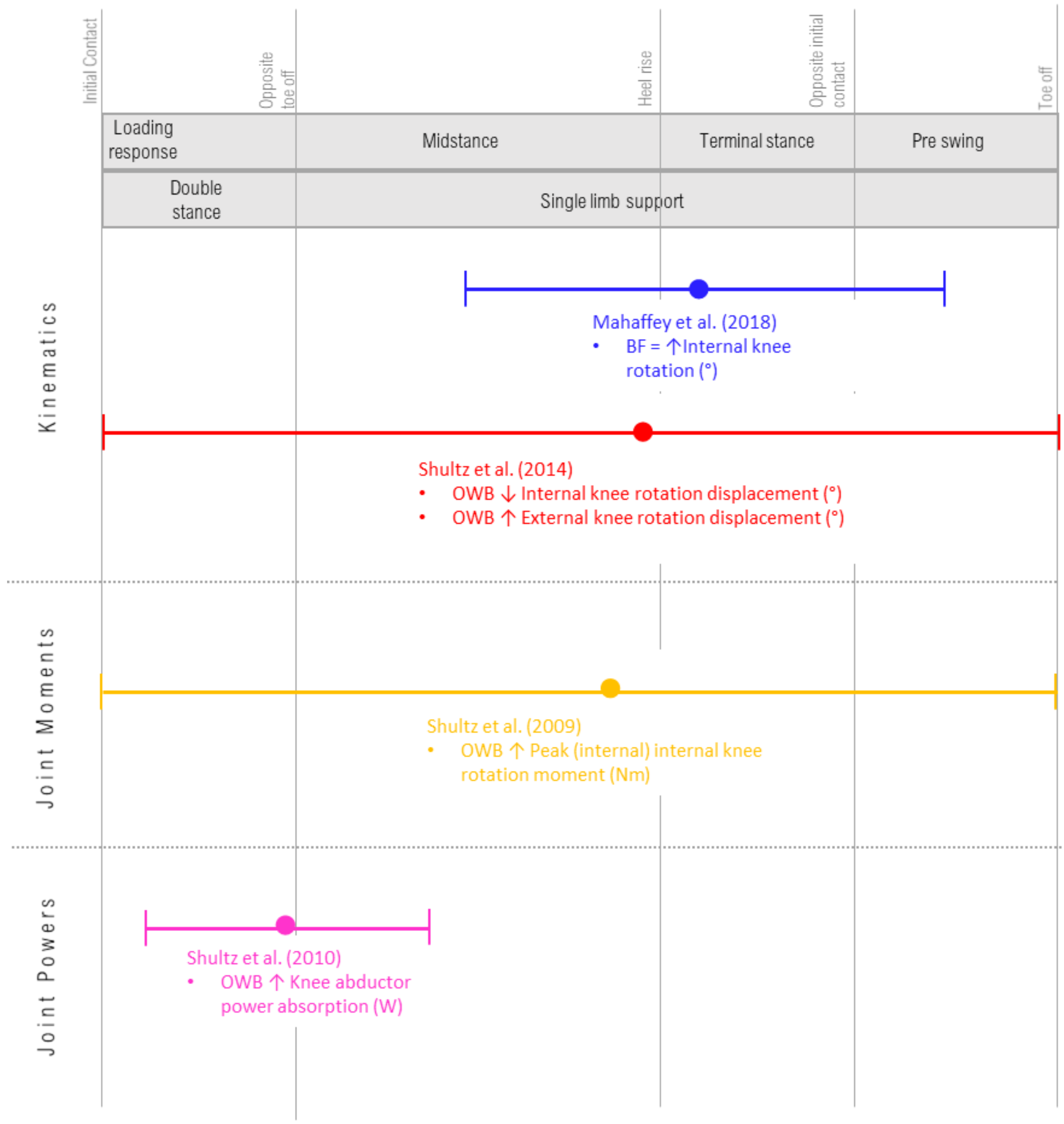

Figure 1-25 Statistically significant differences between overweight and obese and typical weight groups or relationships to body fat reported in children for the knee in the transverse plane during stance phase.

Note: OWB ↓ = overweight obese children reduced, OWB ↑ = overweight and obese children greater, BF= relationship with body fat.

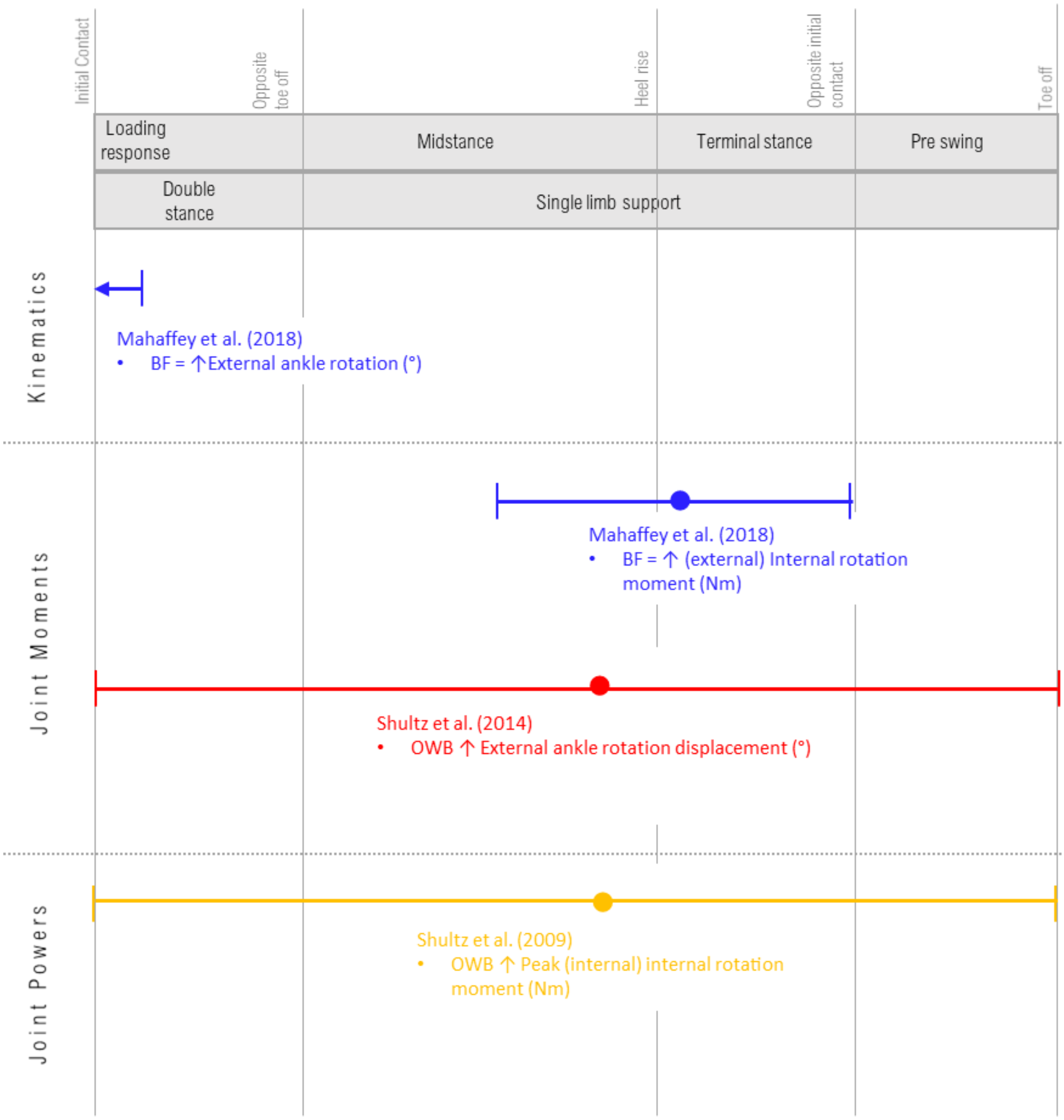

Figure 1-26 Statistically significant differences between overweight and obese and typical weight groups or relationships to body fat reported in children for the ankle in the transverse plane during stance phase.

Note: OWB ↓ = overweight obese children reduced, OWB ↑ = overweight and obese children greater, BF= relationship with body fat.

1.3.5.3 Gait summary.

OWB children adopt adaptive movement patterns to increase stability, such as walking slower with shorter stride lengths, wider step widths, reduced hip and knee range of motion in the sagittal plane, and externally rotated feet to widen the base of support (Gushue et al., 2005; Huang et al., 2013; Mahaffey et al., 2018; Shultz et al., 2014). They also rely more on hip musculature for push-off, rather than the ankle, to reduce knee joint loading, likely due to relative muscular weakness (Mahaffey et al., 2018). These adaptations contribute to greater frontal plane motion at the hip and knee, which is linked to muscle weakness, wider step widths, and hip rotation, increasing the risk of pain and joint instability (D'Hondt et al., 2011; McMillan et al., 2010; Orantes-Gonzalez & Heredia-Jimenez, 2021; Shultz et al., 2014). Flattened and pronated feet, commonly observed in children with OWB, further exacerbate adverse plantar loading patterns and pain risks (Mahaffey, Morrison, Bassett, et al., 2016; Stolzman et al., 2015). Greater body mass increases joint loading, particularly at the knee, elevating the risk of pain and long-term MSK conditions such as osteoarthritis (Gushue et al., 2005; Lerner et al., 2016).

The biomechanical examination of a daily physical function task provides a look at the detailed mechanisms behind the theorised causational links between OWB poor physical function, MSK pain and reduced PA. The compensatory movement patterns adopted by children with OWB, such as reduced stride length, wider step width, and greater reliance on hip musculature to reduce joint loading and increase stability, may limit their efficiency during physical activities, which, when viewed as less capable than TW peers may reduce motivation to participate in sustained exercise. Additionally, the increased joint loading, altered joint motion, and foot pronation observed in children with OWB not only heighten the risk of pain and injury but may also further discourage engagement in PA. These biomechanical differences underscore the importance of tailoring exercise interventions to address the specific needs of children with OWB. Programs should prioritise improving postural stability and muscular strength, particularly around the hips, knees, and ankles. Addressing these gait-related challenges is critical not only to improve physical function but also to break the cycle of reduced PA, and excess mass.

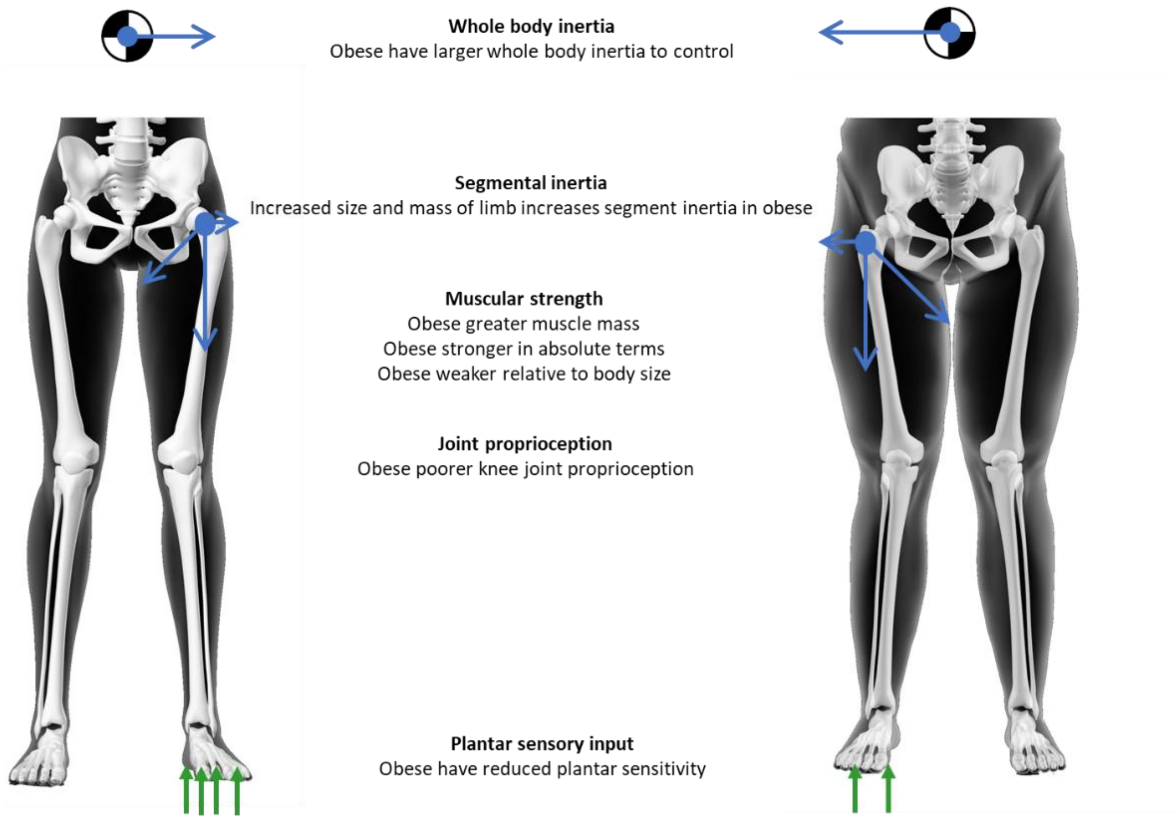

Figure 1-27 Schematic of the different organismic constraints present in people with obesity (Da Rocha et al., 2014; D'Hondt et al., 2011a; D'Hondt et al., 2011b; Saleh et al., 2018; Tomlinson et al., 2016; Wang et al., 2008)

1.3.6 Summary of Physical Function

Physical function deficits in children with OWB are influenced by the constraints of carrying excess mass, which leads to structural and functional adaptations such as altered gait biomechanics, joint misalignment, and compromised performance in physical function tasks. The dynamical systems theory and Newell's model of constraints highlight how interactions between the organism, task, and environment shape motor behaviours. Although the environmental constraint of gravity is always present, children with OWB have an altered (compared to TW children) interaction between themselves and the environment as they are required to support and lift a larger body mass against gravity. Increased mass changes the whole body and segmental inertial properties due to altered mass distribution modifying body geometry (King et al., 2012; Matrangola, et al., 2008). Additionally, children with OWB experience altered foot morphology and decreased plantar sensitivity from altered sensory input, as increased joint compressive loads alter proprioceptive information (Da Rocha et al., 2014; Gentier et al., 2013; Saleh et al., 2018; Wang et al., 2008; Yümin et al., 2016). Increased whole-body and segmental inertial properties, combined with altered sensory input, affect the postural stability system and reduce postural stability (Figure 1-27). Physical function deficits are further exacerbated by lower PA levels, which reduces opportunities to practice motor skills (Kamm et al., 1990; Wrotniak et al., 2006).

Whilst OWB tend to be stronger in absolute terms(possibly a training effect of carrying a larger mass) when strength is examined relative to body size, children with OWB are not as strong as their TW counterparts (Abdelmoula et al., 2012; Blimkie et al., 1989; Maffiuletti et al., 2008; Tsiros et al., 2013). Weakness relative to body mass suggests that children with OWB cannot produce adequate muscular strength for movements that require lifting and controlling body mass. Increased postural instability and lower relative strength result in reduced physical function and the development of altered (less functional) movement patterns (Cilli et al., 2021; Deforche et al., 2009). Postural stability and muscular strength appear to be two main components of understanding physical function deficits in children with OWB.

Childhood obesity has a significant impact on children's general health, especially MSK health and quality of life as they develop. Physical function deficits due to OWB in children are significant and impact participation in daily activities and PA. Reduction in PA feeds into a vicious cycle of increasing obesity, lower physical function, and further reductions in PA (Figure 1-28). Effective interventions are required to improve physical function in children with OWB, and interventions that address postural instability and relative muscular weakness of the lower limb appear to be a justified approach to tackle physical function deficits. Furthermore, biomechanical analysis of a dynamic everyday task such as walking can provide detailed information on how improvements in postural stability and strength alter movement strategies and associated MSK health risks and physical well-being.

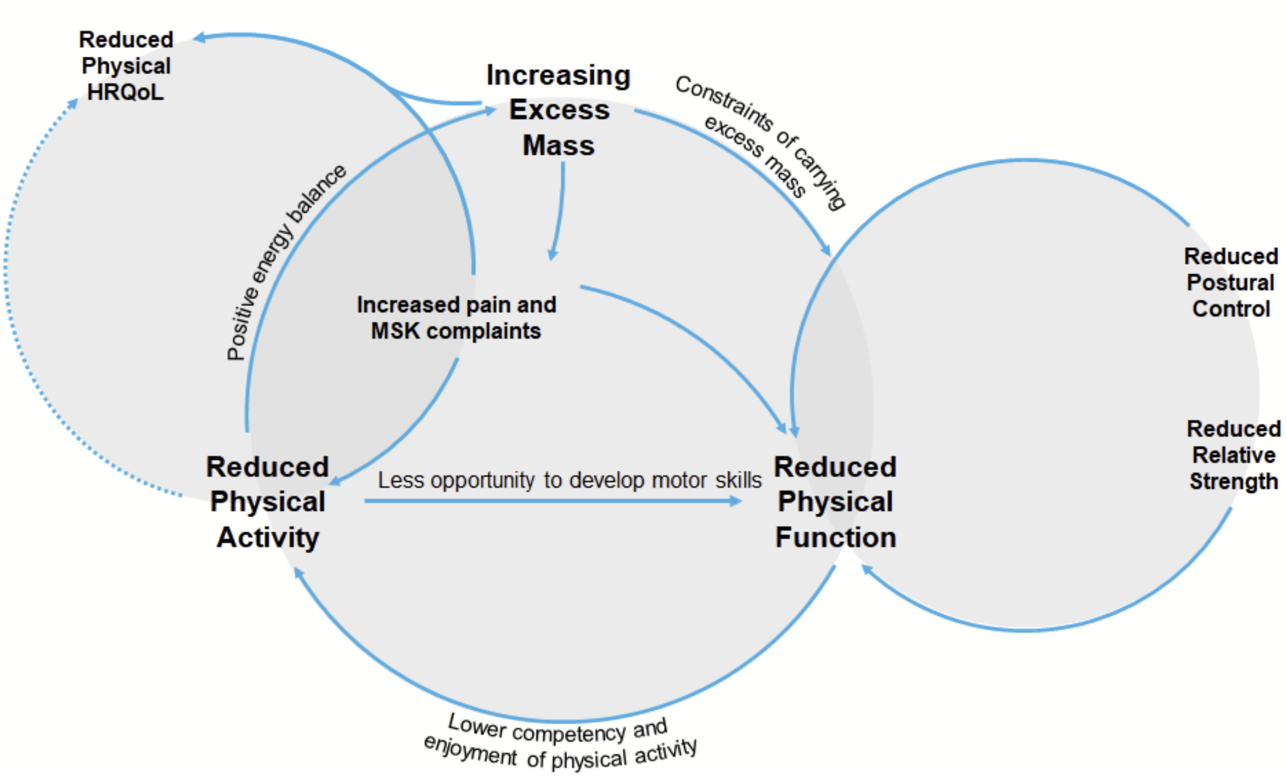

Figure 1-28 Schematic of the interacting components of physical function, physical well-being and negative cycle of increasing excess mass in overweight and obese children.

1.4 Interventions in children with overweight and obesity

Weight loss interventions in children with OWB typically centre around dietary restriction and a combination of aerobic and anaerobic exercise to achieve a calory deficit and resultant weight loss. As body mass reduces, so do the constraints of carrying a larger mass on the motor control systems, and the ratio of strength to body size becomes more favourable. However, restrictive calorie intake may be harmful, and guidelines for treating childhood obesity focus more on healthy eating behaviours than set calorie restrictions (Balantekin et al., 2014; National Institute for Health and Care Excellence, 2014). Moreover, improvements in physical function after a weight loss intervention are only partially explained by weight loss (D'Hondt et al., 2011). Exercise components included as part of weight-loss interventions may have a greater effect on physical function in children with OWB than weight loss alone. Therefore, it may be more appropriate to address physical function and PA to impact the negative cycle of childhood obesity, as previously outlined in the physical function summary (1.3.7). Exercise interventions focused on improving postural stability and muscular strength may be a superior way to address functional deficits in children with OWB than weight loss-specific interventions as improvement in physical function may have longer-term benefits on motor competency and motivation for PA. The following Sections (1.4.1 and 1.4.2) review exercise intervention studies measuring postural stability and/or muscular strength outcomes in children with OWB. The key concepts for review relate to intervention design (i.e. the content, duration, and intensity of implemented interventions) and the effectiveness of these interventions to bring about change in postural stability (such CoP measures or inference of stability from performance in balancing tasks), or muscular strength (i.e. grip strength, jump height, 1RM and isokinetic dynamometry).

1.4.1 Exercise intervention effects on measures of postural stability

Exercise interventions in children with OWB examining potential changes in a measure of postural stability have varied intervention designs (Table 1-12). Six months of ball games were effective in improving one-legged standing performance in 6-12-year-old children with OWB (Kuni et al., 2015). Ball games increased exposure to locomotor and object control motor skills that would have challenged the postural stability system, thereby bringing about the adaptation reported. Similarly, 12 weeks of plyometric training (lateral jumps, squat jumps, platform jumps, and one-legged jumps) was effective in improving balance while walking backwards on a beam in 7-9-year-old children with OWB (Nobre et al., 2017). Plyometric training is an alternative training modality that stimulates the neuromuscular system through high-intensity exercises requiring high rates of force production, power, and eccentric control (Jeffreys et al., 2016). The increase in postural stability from plyometric training may be due to more efficient muscle recruitment patterns and an increase in motoneuron discharge rate (Gruber et al., 2007). Despite no reported injury by Nobre et al. (2017) some consideration must be given to the increased joint loading plyometric training would place on children with OWB who are already experiencing increased and adverse loading on lower limb joints. Moreover, whilst improvements in stability were inferred from performance during balancing backwards on a beam task, it has limited relevance to postural stability limitations of daily tasks, thus providing little insight into children's daily functional ability.

Guzmán-Muñoz et al. (2019) used an integrative neuromuscular programme consisting of exercises to increase strength and agility (mini hurdle jumping, cone drills, ladder drills) and exercises aimed at balance and coordination (SLS, marching, single-leg squat) on progressively unstable surfaces. Guzmán-Muñoz et al. (2019) reported improved biomechanical measures of static stability after four weeks of training in 7-9-year-old children with OWB. The combination of balance, plyometric, and coordinative exercises (mini hurdles, agility drills, single-leg balance, marching, tandem walking, and single-leg squat) used by Guzmán-Muñoz et al. (2019) is a similar programme used successfully to improve motor skill in healthy child populations (Faigenbaum et al., 2014) and advised for school-aged children to improve athletic performance and reduce the risk of sports injuries (Myer et al., 2011). The varied interventions and different outcome measures reported by Kuni et al. (2015), Nobre et al. (2017), and Guzmán-Muñoz et al. (2019) make it difficult to determine the best approach to increase stability in children with OWB, but each reported a benefit to stability in their respective test. The effect of exercise interventions in children with OWB on biomechanical dynamic stability measures is unknown. Moreover, any beneficial impact of improving postural stability (such as the theorised benefit to daily tasks of physical function measures or physical well-being, including PA) in OWB from the reviewed studies is not reported.

Table 1-12 Summary of intervention studies measuring postural stability as an outcome measure in overweight and obese children.

Study	n	Age	Intervention and control groups	Intervention duration	Attendance	Postural stability measure	Main findings
Kuni et al. (2015)	46 OWB	6-12 years old	1) Ball games 2) Nutrition Counselling 3) Ball games and nutrition counselling 4) No intervention	6 Months Ball games 90 min, 2 x week	Required to include in analysis: 70% ball game participation 6/9 Counselling sessions n= 3 non-compliant in ball games	One minute SLS on gymnastics mat, in eyes open and eyes closed conditions, count of errors.	Intervention groups 1 and 2 significantly improved stability in the eyes open condition. Reduction in error points- Group 1) 5.6 ± 3.5, T = 5.264 Group 2) 6.0 ± 6.3, T = 3.324 No significant difference in groups 3 or 4 No difference in eyes closed conditions.
Nobre et al. (2017)	59 OWB	7-9 years old	1) Plyometric training 2) No intervention	12 weeks 20 min, 2 x week	Not reported	Balancing backwards score	Intervention group significant improvement in balancing backward score
Guzmán-Muñoz et al. (2019)	32 OWB	7-9 years old	1) Neuromuscular training 2) No intervention	4 weeks 20 min, 2 x week	Required to include in analysis: 85%	CoP during bilateral stance with eyes open and eyes closed. Star excursion balance test score	Stability improved in the intervention group. Eyes open mean CoP velocity reduced -15.7 m/s Eyes closed CoP area -52.6 m^2 . Star excursion balance test score increased. Anterior 56.7 % Posterior-medial 12% Posterior-lateral 45.1%

Note: CoP=Centre of Pressure, OWB = Overweight and obese, SLS= Single leg stance

1.4.2 Exercise intervention effects on measures of muscular strength

A variety of interventions have been successful in improving strength measures in children with OWB (Table 1-13). Increases in jump height or distance have been reported following eight weeks of resistance training (3x per week; McGuigan et al., 2009) and 12 weeks of plyometric training (Nobre et al., 2017). While improvements in jump performance are typically associated with enhanced power production, McGuigan et al. (2009) found no improvement in jump power despite increased jump height. This suggests that children with OWB in McGuigan et al. (2009) study were able to produce greater force but not generate it more quickly. However, Sgro et al. (2009) reported significant improvements in jump power after 16 weeks but not at week 8 of combined resistance training and explosive exercises (3x per week) indicating that developing greater power production may require a longer training duration. Alternatively, the inclusion of explosive exercises alongside resistance training by Sgro et al. (2009), compared to resistance training alone by McGuigan et al. (2009), may have enabled participants to improve their ability to generate force more rapidly rather than solely increasing strength. Increases in 1RM tests (squat or leg press) have been reported after eight weeks (3 x week), 12 weeks (3 x week) and five months (2 x week) of resistance training in children with OWB (Alberga et al., 2013; McGuigan et al., 2009; Treuth et al., 1998). Resistance training interventions have gained popularity as they often allow OWB to outperform TW peers due to greater absolute strength, which may improve psychological well-being (Schranz et al., 2013). Resistance training appears to be effective in increasing strength as measured by 1RM in children with OWB compared to OWB controls (no intervention), even after short training periods (eight weeks). However, 1RM tests may overestimate increases in strength. Gentil et al. (2017) demonstrated that after 11 weeks of resistance training, 1RM leg press improvements were significantly greater (+ 8 %) than torque increases in knee extension measured by isokinetic dynamometry. 1RM tests may further benefit from neurologic adaptations as the 1RM tests replicate the trained movements, and muscular coordination is improved (Carroll et al., 2001). The disparity in strength increases may be a result of specific skill improvement over strength adaptation (Buckner et al., 2017).

Horsak et al. (2019) measured isometric knee extension and hip abductor strength using hand-held dynamometry before and after 12 weeks (two sessions per week) of lower limb strength and neuromuscular intervention (table 1-13). Only hip abductors were significantly (+30%) stronger post-intervention (Horsak et al., 2019). The ratio scaling of strength to body mass may not have been optimal, as previously discussed (Section 1.3.3.3). Alternatively, the intervention may not have been effective in significantly increasing knee extension strength relative to body size. Interestingly, Horsak et al. (2019) is the only reviewed study to include additional measures of physical function and well-being as a result of interventions. Horsak et al. (2019) reported no significant improvement in knee pain and altered frontal plane hip motion during gait. Investigation of the effects of improving strength on markers of physical well-being and physical function are warranted given their theorised relationship in cross-sectional research (Ross et al., 2016; Tsiros et al., 2020) and inclusion in the ICF model of disability and functioning. Resistance training improves strength, but more studies using isokinetic dynamometry are needed to assess its effects on all lower limb muscle groups, including key functional muscles like hip extensors and plantar flexors, which remain under-researched in children with OWB. Moreover, whilst reliability for some measures of strength, specifically in children with OWB, has not been reported as previously discussed (Section 1.3), neither have measurement error or the minimal detectable change (MDC - the smallest change in a score that can be detected beyond any random error).

Whilst the reviewed interventions appear successful in increasing measures of strength in children with OWB, several studies noted high dropout rates or poor attendance during the course of interventions (Table 1-13), and studies exclude those with low attendance (i.e. attendance below 85%) from the analysis. Ideally, all recruited participants would receive the fully designed intervention to be tested to be able to ascertain its effectiveness on outcomes. However, what must be considered is the experience of participants, particularly those who do not attend interventions, and their motivations to adhere or not to prescribed exercise interventions (Dishman, 1985). If exercise interventions are to reach their intended goal of bringing about a beneficial outcome to a population, components and barriers to them adhering to it (i.e. time, economic, psychological, and motivation) must be considered (Dishman, 1985.; Dishman et al., 2005).

Table 1-13 Summary of intervention studies with muscular strength as an outcome measure in overweight and obese children.

Author	n	Age	Intervention and control groups	Intervention duration	Attendance	Muscular strength measure	Main findings
Nobre et al. (2017)	59 OWB	7-9 years	1) Plyometric training 2) No intervention	12 weeks 20 min, 2 days/ week	-	Hand grip strength Standing long jump	The intervention group had significant increases in hand grip strength, and standing long jump.
Sgro et al. (2009)	31 OWB	7-12 years	1) Resistance training 8 weeks 2) Resistance training 16 weeks 3) Resistance training 24 weeks	8, 16 or 24 weeks 45-60mins, 3 days/ week	Training compliance 1) 83 ± 36 % 2) 89 ± 12 % 3) 89 ± 7 % 19 participants withdrew.	Squat jump power	Group 3 had a significant increase of 10.5% in squat jump power at week 16.
McGuigan et al. (2009)	48 OWB	7-12 years	1) Resistance training	8 weeks 3days/ week	Training compliance 89 ± 7% 15 withdrew before week 8.	1RM squat Squat jump power Squat Jump height Countermovement jump power Countermovement jump height	1RM squat significantly increased 22.3 ± 8.7 vs 38.8± 16.1 kg. Squat jump height increased 23.1 ± 7.9 vs 26.7 ± 7.3 cm Countermovement jump height 19.5 ± 6.2 vs 22.1 ± 5.3 There was no significant change in jump power.
Alberga et al. (2013)	19 OB	8-12 years	1) Moderate intensity high repetition resistance training. 2) No intervention	12 weeks 75 min, 2 days/ week	98% compliance rate	1RM leg press	1RM leg press increased in the intervention group 89.4 ± 30.3 to 113.4 ± 32.7 kg The intervention group had a significantly different increase of 28.9 ± 12.5% 1RM leg press compared to 10.3 ± 12.4% in the control group.
Treuth et al. (1998)	11 OB	7-10 years	1) Low-volume strength training	5 Months 20 min, 3 days/week	Attendance was 83% (70% in last month due to academic tests) One dropped out	1RM leg press Isometric knee extensor strength	The intervention group had a 20.0% increase in 1RM leg press and a 35.2% increase in isometric strength of the knee extensors.
Horsak et al. (2019)	35 OB	10 -18 years	1) Strength and neuromuscular exercise programs 2) No intervention	12 weeks 60min, 2days/week	Attendance 57%	Isometric knee extensor strength. Isometric hip abductor strength.	Significant % increase in hip abductor strength in the intervention group.

Note: 1RM = One repetition maximum, OB= Obese, OWB = Overweight and Obese,

1.4.2.1 Interventions in overweight and obese children summary

Resistance training and exercises that affect the postural control system (unilateral, dynamic and plyometric movements) show the potential to improve strength and postural stability in children with OWB. Balance training exhibits the ability to improve postural stability in a relatively short period (four weeks), and resistance training (through either the use of gym equipment or lower-cost resistance band and bodyweight exercises) improves strength over a minimum period of 8 weeks. There is a lack of studies examining the effects of resistance training on postural stability measures. Whilst exercise interventions appear promising, it must be noted that studies report low attendance (<70%) and high dropout (>20%) rates (table 1-12 and 1-13). Low attendance and adherence limit the application of findings and highlight the need to consider how interventions are delivered to children. If exercise interventions are to be effective, they must be attractive to children and meet their needs. It should also be encouraged that children with OWB develop positive relationships with exercise and PA through enjoyment to continue exercising after interventions and to incorporate those activities into daily life.

1.4.3 Children's motivation to engage in exercise and physical activity.

To understand children's engagement with exercise interventions and PA as a healthy behaviour beyond those interventions, it is important to understand children’s motivation to be active. Common barriers to exercise interventions in children and adolescents include time constraints, locations and negative experiences (Holt et al., 2020). Interventions that are based within the school setting during the school day may address several barriers, but school-based studies still report high drop-out and low adherence (McGuigan et al., 2009; Treuth et al., 1998). Improving adherence and, understanding what motivates children to engage in activity interventions, is important to improve intervention effectiveness (Han et al., 2018).

Motivation lies on a continuum of self-determination (Figure 1-29) covering different types of motivation (controlled to autonomous); where someone lies on the continuum is dependent upon the degree to which social context supports basic psychological needs (Ryan & Deci 2017). Self determination theory (SDT) is centred around quality and type of motivation rather than a single magnitude metric. High-quality motivation is associated with healthy development and well-being and is connected with motivation type and regulation at the more self-determined end of the continuum (Ryan & Deci, 2017). Motivation quality is enhanced by the satisfaction of basic psychological needs (autonomy, competency, relatedness; BPN) and depleted by need frustration (Deci & Ryan, 2008).

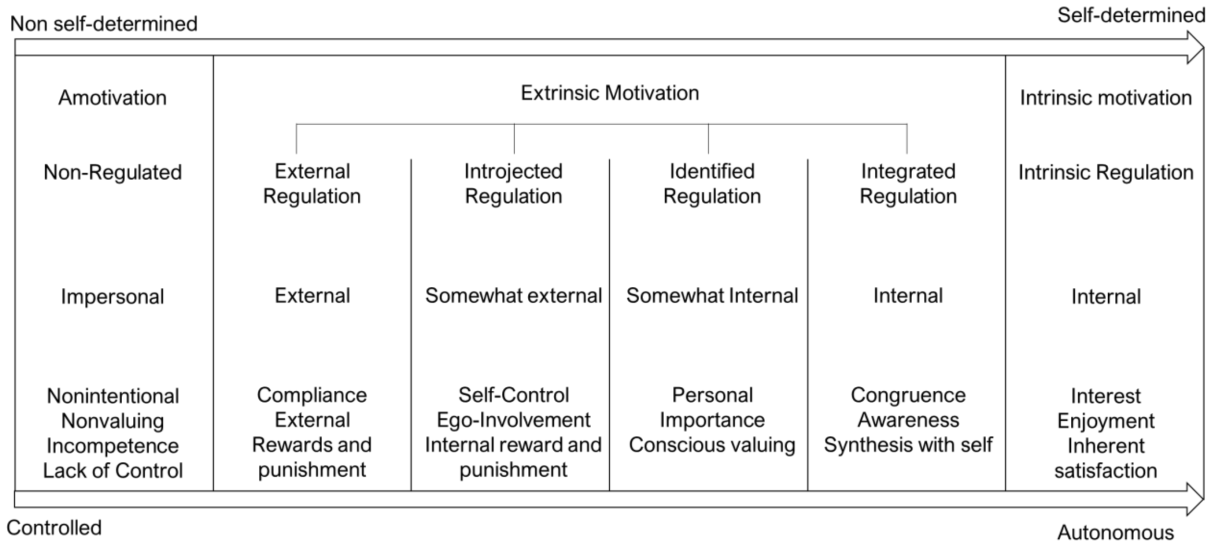

Figure 1-29 Self-determination continuum based on Ryan & Deci (2000).

1.4.3.1 Basic Psychological Needs

Children's development and well-being are clearly and functionally influenced by measurable phenomena known as BPN (Ryan & Deci, 2017). BPN are feelings of autonomy, feelings of competence and feelings relatedness. Autonomy refers to the need for children to be able to determine their own actions (self-regulation) and not from external forces (Ryan & Deci, 2000). In an autonomy-supportive environment (versus a demanding and controlling environment), children are afforded a choice and encouraged to self-regulate (Ryan & Deci, 2017). Competence is the need for children to feel they have a sense of mastery in a given action or skill. In a competence-supportive environment (versus overly challenging or discarding), children are provided structure and positive informal feedback (Ryan & Deci, 2017). Relatedness is the need for children to have a feeling of social connectedness and belonging to others in the same environment (e.g. intervention sessions). In a relatedness-supportive environment (versus impersonal or rejecting), children feel cared for by others and feel significant to others. BPN may be supported or thwarted by intervention design and delivery which may impact the feeling of BPN satisfaction.

1.4.3.2 Motivation quality

As proposed by SDT, motivation is not one single phenomenon, but a quality defined by different motivation types (intrinsic, extrinsic, and amotive). Motivation types differ in magnitude, source, and behavioural outcomes (Ryan & Deci, 2017). Different types of motivation are characterised on the autonomous-to-controlled continuum by how well each represents autonomous versus controlled regulation. For example, intrinsic motivation characterised by integrated regulation encouraged by an autonomous supportive environment will generate positive behavioural outcomes through better motivation quality (Figures 1-30 and 1-32).

1.4.3.2.1 Intrinsic motivation

Intrinsic motivation relates to behaviours performed out of interest or simply for the enjoyment of doing so. Intrinsic motivation represents the highest quality motivation at the top end of the autonomous end of the continuum. Cognitive evaluation theory (CET), a mini theory within SDT, focuses on how the social environment affects intrinsic motivation. CET stipulates that events that negatively impact feelings of autonomy and competence will reduce intrinsic motivation (Mandigo & Holt, 2013). Furthermore, CET suggests that in activities with a social element, such as PE classes in a school setting, relatedness will also play a conducing role in intrinsic motivation (Mandigo & Holt, 2013).

1.4.3.2.2 Extrinsic motivation

Extrinsic motivation relates to behaviours controlled by external factors. Extrinsic motivation may be more autonomous (done for a valued outcome such physical improvement) or controlled (done to avoid punishment such being told off for not taking part in an activity), depending on the degree of internalised regulation (Ryan & Deci, 2017). SDT proposes four types of regulatory styles (Figure 1-30) determined by varying motives characterised across a controlling and autonomous continuum.

	Regulatory style	Motive
Autonomous	Integrated Regulation	Behaviour aligns with values and beliefs
	Identified Regulation	One accepts the value of the behaviour.
	Introjected Regulation	Not entirely accepted the value in the behaviour but is motivated by external oversight such as guilt or fear of disapproval.
Controlling	External Regulation	Directly controlled by outside forces.

Figure 1-30 Autonomous – controlling continuum of extrinsic motivation and motive regulation (Ryan & Deci, 2000).

1.4.3.2.3 Amotivation

Amotivation is at the extreme non-self-determined end of the motivation continuum and is defined as lacking purpose, intentionality, and motivation. Whilst amotivation is represented as one behavioural outcome, different contexts may drive it, i.e. lack of control or lack of competence, lack of interest or value in the behaviour, or defiance and motivated non-action (Ryan & Deci, 2017).

1.4.3.3 Self determination theory in exercise and physical activity

SDT is commonly applied to examine the relationship between motivation and PA (during daily life) or exercise (specific times of programmed activity) in children. Meta-analyses reviewing the relationships between motivation quality and physical outcomes in children and adolescents report a positive relationship between autonomous motivation and PA and a negative relationship between controlled motivation and PA, and autonomous type motivation as positively correlated with positive adaptive outcomes (cognitive, affective, and behavioural; Owen et al., 2014; Vasconcellos et al., 2020). Moreover, autonomous types of motivation are also associated with greater outcomes in skill development during PE than controlled types of motivation (Boiché et al., 2008). These systematic reviews are not OWB-specific but incorporate studies that combine TW and Participants with OWB.

The motivational sequence of social environment as a predictor of perceptions of need satisfaction and the resultant effect on motivation and behaviour was first proposed by Vallerand (1997) (figure 1-31). Autonomy supportive environments are social contextual environments more likely to satisfy psychological needs than a controlling environment and have positive effects on motivation and outcomes (Deforche et al., 2011). Studies that have manipulated social contextual environments to be more autonomy supportive (for example through changing how teachers provide feedback in PE classes or providing children greater choice over activities) found positive outcomes on enjoyment and PA behaviour (Deforche et al., 2011; Van den Berghe et al., 2014).

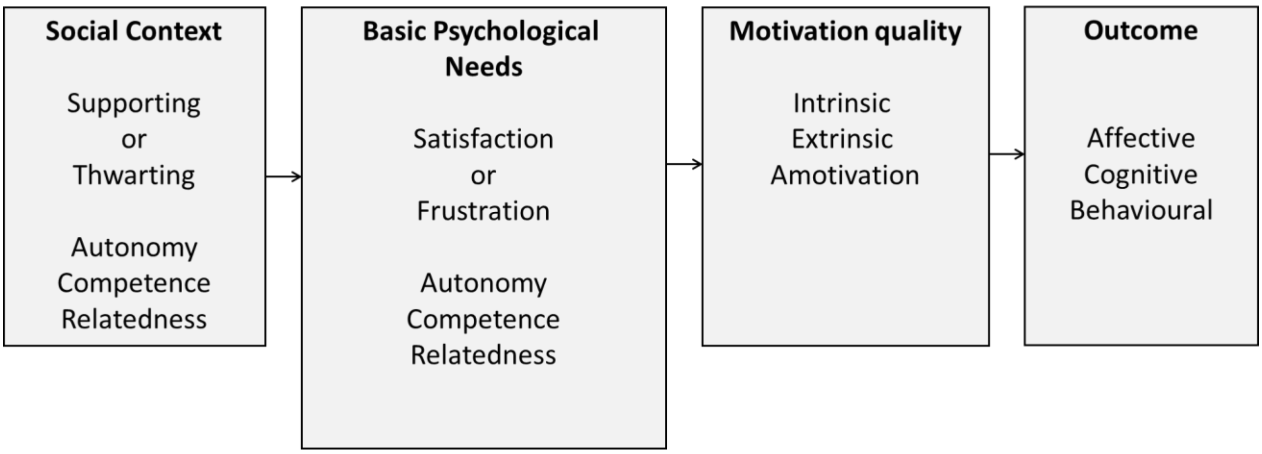

Figure 1-31 The motivational sequence of social context to outcome (Vallerand, 1997).

Children's motivation for PA is based on enjoyment and the inherent satisfaction of the activity through social contexts that support the satisfaction of BPNs, promoting more autonomous motivation types (Leptokaridou et al., 2015; van Aart et al., 2015). Children who experience BPN satisfaction enjoy PE classes more, which, in turn, predicts their effort during PE classes (Leptokaridoui et al., 2015). Through focus groups discussing the enjoyment of PE, Domville et al. (2019) provided qualitative evidence to support that satisfying BPNs through providing choice, allowing children to feel competent yet appropriately challenged, and fostering interpersonal relationships with peers and teachers, creates an environment where children enjoy PE classes. Giving students more autonomy with a choice of activities increases intrinsic motivation and can result in greater PA during PE classes (Prusak et al., 2004; Ward et al., 2008). When given a choice, children are more likely to choose activities that they inherently find more enjoyable (Deforcher et al. 2011, Domville et al., 2019). In a study of obese girls (8-12-year-olds) who either completed a strict aerobic exercise programme or were given a choice of childhood activities, those in the choice group lost more weight during the eight-week intervention period (Epstein et al., 1982). However, those in the aerobic group showed greater fitness increases (measured by step test), suggesting that obese children who chose their own activities did not exercise to the same intensity. Despite greater increases in fitness post-intervention (2 months), these levels were not maintained in the aerobic group, whereas the choice group maintained their fitness level to follow up (17 months). The maintenance of fitness suggests that the choice group enjoyed the activities and were motivated to continue PA after the intervention (Epstein et al., 1982).

Enjoyment and motivation of PA participation additionally depend on children's perception of their own competence (Deforche, 2011; De Meester, 2016). De Meester et al. (2016) demonstrated that adolescents who over-perceived their motor competence reported greater motivation for PE than those who accurately perceived their motor competence. Given the low motor competence and perceived motor competence seen in children with OWB (Spessato et al., 2012) developing their perceived competence may be important to motivate them to be physically active. Moreover, feelings of competency and autonomous forms of motivation are important in developing new motor skills (Kalaja et al., 2009). In a study of 370 young adolescent (13 years old) boys and girls, Kalaja et al. (2009) demonstrated the association between feelings of competency and autonomous supportive environment on locomotor and object manipulation skills. Domville et al. (2019) reported that children enjoy PE when activities are tailored to their abilities (i.e. activities that are challenging but not too hard to discourage development) and when they feel supported and encouraged by teachers and peers when learning new skills.

In focus groups (n = 36 healthy children, 9–13-years-old) discussing their experience of a school-based PA intervention, participants reported that a sense of relatedness was pivotal to students' well-being and influenced feelings of autonomy and competence (Holt et al., 2018). Van Aart et al. (2015) reported that teacher-relatedness was the most important predictor of autonomous types of motivation in PE; the second was classmate-relatedness (only in boys). Classmate behaviour affects feelings of relatedness (i.e. criticism or support from peers), impacts enjoyment, and, combined with feelings of autonomy, mediates effort during PE classes in primary school-aged children (Domville et al., 2019; Leptokaridou et al., 2015). Domville et al. (2019) reported that children enjoy PE more when teachers show that they care, get involved, and are supportive. Furthermore, Vaan Art et al. (2015) suggest that if teachers can foster positive interpersonal relationships, they can autonomously motivate children during PE regardless of competency.

Autonomous supportive PE environments positively impact motivation, which is maintained over school terms, whereas more controlled environments cause motivation to deteriorate as the terms progress (Leptokaridou et al., 2016). Autonomy-supportive environments are possible in school settings despite constraints, which often leave less space for choice (Sun & Chen, 2010). For children to enjoy and engage with a school-based exercise intervention and successfully develop strength and motor control skills, it is clear that the social environment must support the satisfaction of BPNs. Furthermore, it may be essential to foster feelings of competence in children with OWB, which teachers or those holding exercise sessions may support. Moreover, it is important to make sure exercise interventions with OWB do not thwart BPN satisfaction, which may then impact PA behaviour outside and beyond the intervention. Whilst many of the cited studies are not specific to children with OWB, it has been demonstrated that satisfaction with BPN and autonomous environments positively relate to PA behaviours in OWB (Gourlan et al., 2013; Verloigne et al., 2011; Zhang & Qian, 2022). However, children with OWB may require additional support to feel satisfaction of BPN, particularly from teachers in the PE setting (Zhang & Qian, 2022).

1.4.4 Summary of self determination theory in exercise and physical activity.

SDT suggests that when children's basic psychological needs (autonomy, competence, and relatedness) are satisfied, they are more intrinsically motivated and likely to enjoy and engage in PA or exercise (Ryan & Deci, 2008; Leptokaridou et al., 2016). Satisfaction of BPN during PE classes can be achieved by providing choice, allowing children to feel competent yet appropriately challenged, and fostering interpersonal relationships with peers and teachers, creating an environment where children enjoy PE classes (Domville et al., 2019). The application of SDT has been applied to PE delivery and found beneficial effects on attendance (Edmunds et al., 2010) but is yet to be applied to exercise interventions for children with OWB. Given the low PA engagement and reportedly low motor competence seen in children with OWB, BPN support may be critical to motivating them to be physically active.

Interventions to increase strength and postural stability typically involve repetitive movements or exercises performed 2 to 3 times a week for several weeks. These interventions are likely to foster a controlling environment rather than an autonomous, supportive environment. Therefore, they are unlikely to meet the BPN of children, which may partially explain low adherence and high attrition rates. However, some studies still report attendance and adherence rates of >90% attendance, this is likely through techniques such as one-on-one training (Alberga et al., 2013) and requiring parents to pay for exercise sessions (Huang, 2014). Rewards for attendance are likely to foster a more controlling environment and cultivate more external motivation (rather than greater quality intrinsic or self-identified motivation). Therefore limiting any residual benefit to PA once the intervention ends and generates a more negative experience and relationship with PA. Exercise interventions need to be effective and positive experiences for children with OWB, requiring a holistic approach. Negative experiences in PE and exercises settings later impact PA participation through life stages, further exacerbating the negative cycle of OWB and PA (Brown, 2014; Thiel et al., 2020).

1.4.5 Co-production as a methodology to improve intervention design for overweight and obese children.

Design of exercise interventions in children with OWB has previously focused on theories of physical adaptation and likely not met the needs of children, resulting in low attendance and high dropout (Section 1.4.2). Steps must be taken to holistically approach the needs of children whom interventions are designed for. Co-production remains inconsistently defined and reported. Terms such as co-creation, co-design, participatory research, and co-research are often used, reflecting the varied ways in which these methodologies are applied (Messiha et al., 2023; O'Mara-Eves et al., 2022). Rather than a single true definition, co-production is typically characterised by commonly stated values in its approach, including equality, diversity, social justice, relationship-building, and mutual learning (O'Mara-Eves et al., 2022; B. Smith et al., 2023). However, these principles must be adapted to the specific context of the research area to ensure relevance and effectiveness (Smith et al., 2023). The term co-production will be used throughout the thesis as a term to describe a method of engaging stakeholders in research to create meaningful, context-specific decisions that aim to be impactful.

Co-production is often used in public health services but is becoming an emerging methodology within sport, exercise and health research for its potential to enhance the impact and relevance of research outcomes (Smith et al., 2023). A co-production approach involves the collaborations between researchers and stakeholders- such as patients, service users, or specific target populations—throughout the research process (Smith et al., 2023). There have been recent calls for research to take place 'with' stakeholders (and not just 'to' them) in many sport, exercise and health disciplines (Smith et al., 2023). Moreover, the use of co-production methods have been suggested to be incorporated into obesity-related intervention and school-based intervention developments (Ells et al., 2018; Lister et al., 2023; Reed et al., 2021) as a means to tailor interventions and improve delivery style in the hopes of mitigating common issues such as low attendance, high attrition rates and poor compliance in child OWB exercise interventions (Ellis et al., 2018).

The value of co-production is in the potential to centre research on the lived experiences of target populations, ideally leading to more effective and impactful outcomes (Hickey, 2018). This is particularly evident in research aimed at school-based interventions, where a co-production approach allows the target population (i.e. children, teacher, and or parents) to participate in decision-making during intervention development (Reed et al., 2021). By including those who aim to benefit from interventions, researchers can develop interventions that are practical and acceptable (Ells et al., 2018). However, several barriers to successful co-production work exist in academic research, including time and resource demands of the process, as well as the financial and emotional costs to stakeholders involved (Williams et al., 2020). Clearly defined and context specific aims that account for stakeholders and resources are essential to ensuring co-production can be incorporated meaningfully. Co-production has been successfully implemented in obesity and activity intervention design and typically is underpinned by frameworks (i.e. design thinking process, intervention mapping) and or theoretical theories (i.e. social cognitive theory, behaviour change theory; Anselma et al., 2019; Clifford et al., 2023; Hall et al., 2020; Mackenzie et al., 2021). Methods to engage with stakeholders (usually the target population or those that work with them) typically involve multiple workshops and or semi-structured interviews, depending on the needs and context of the intervention. For example, Mackenzie et al. (2021) utilised two one-hour workshops with office employees (limiting time and cost demands) to develop an intervention to reduce sedentary behaviour based on social cognitive theory. Contrastingly, Alsema et al. (2019) used a co-production approach and intervention mapping framework to design, produce, and plan the implementation and evaluation of a childhood obesity prevention programme. Anslema et al. (2019) engaged 9 to 12-year-old children over regular workshops for two years, which is arguably more time costly but appropriate for the research aims, applied framework and context. In comparison Hall et al. (2020) utilised 5 workshops with stroke survivors and carers to develop an activity intervention informed by behaviour change theory. Similarly, Clifford et al. (2023) engaged primary aged school children, teachers and school leaders over six phases (4 adults workshops and 2 child workshops), utilising design thinking to design a school-based motor competence and mental health intervention. Clifford et al. (2023) do note several challenges to engaging teachers and school leaders in co-production work due to the high workloads of the school curriculum and trying to timetable these activities with multiple teachers. Despite a broad range of co-production approaches to intervention design and development, each is shaped by research aims and context. Knowledge gathered from the lived experience of target populations is integrated with existing research evidence to guide discussion and inform intervention development and design. Co-production prioritises the integration of the lived experiences of target populations and alignment with real-world needs. Therefore, there is limited direct evidence comparing the effectiveness of co-produced interventions versus non-co-produced interventions, as the focus is typically on the added value of collaboration rather than solely on quantitative outcomes. However, it does appear that co-production can be implemented with the aim of enhancing theoretical models of intervention effectiveness by improving participant enjoyment, engagement, and relevance.

1.4.6 Conclusion of interventions in children with overweight and obesity.

Interventions in children with OWB show that exercises which include balance training and resistance training have positive effects on postural stability and muscular strength. However, a range of intervention exercises, study lengths, and outcome measures make comparison across studies difficult. More research is needed to determine the effects of different interventions on postural stability, muscular strength, and physical function. Moreover, few intervention studies report the effects of interventions on key components of OWB, such as PA, pain, and HRQoL. Exercise interventions in children with OWB to improve postural stability and muscular strength do not consider the basic psychological needs of children and, therefore, experience low attendance and poor attrition. It is essential to understand how children feel about and experience exercise sessions to foster a positive relationship with PA. A co-production approach to intervention development may be an appropriate method to understand the needs of children by directly engaging them in an intervention development process that may also be informed by previous intervention findings and underpinned by SDT theory.

1.5 Thesis Aims

Effective interventions are essential to disrupt the negative cycle of increasing body mass, reduced physical function, and low levels of PA experienced by children with OWB. Improving postural stability and relative muscular strength may offer a pathway to improve physical function and potential impact on physical well-being in children with OWB. Previous interventions targeting children with OWB have used a variety of approaches to improve postural stability and muscular strength and have employed a diverse range of outcome measures. The reliability and MDC for many of these outcome measures have not been established in children with OWB. Additionally, psychological factors influencing the uptake and sustained effect of exercise interventions are often overlooked.

Therefore, the aims of this thesis are as follows:

- To assess the reliability and change statistics of key physical function measures, including isokinetic dynamometry, biomechanical dynamic postural stability, and gait assessment, in children with OWB.
- To design, pilot, and refine a feasible, school-based exercise intervention aimed at improving postural stability and muscular strength in children with OWB while also addressing the psychological needs of children with OWB.
- To evaluate the effectiveness of this intervention to improve postural stability and muscular strength, and to determine its impact on physical well-being and physical function in children with OWB.

The novelty of this work lies in several aspects. First, it establishes MDC values for various physical function outcomes specific to children with OWB, aiding in the assessment of intervention effectiveness. Second, it involves the piloting and co-development of a school-based exercise intervention directly with children, enhancing both acceptability and potential impact for Participants with OWB. Finally, this thesis examines the effects of an exercise intervention on physical function, supported by detailed biomechanical analyses, and possible impact on physical well-being, whilst also providing key information on attendance and adherence that may be used to support further use of a co-production approach to exercise interesting design in children with OWB.

2 General Methods

This chapter details the data collection and data processing methods used in experimental Chapters 3, 4, and 6 to measure participant anthropometrics and body composition, physical well-being (pain, physical health related quality of life [HRQoL], and physical activity [PA]) and physical function (postural stability, muscular strength, clinical tests of physical function and 3D gait analysis).

2.1 Anthropometrics and body composition

Height and body mass were measured in the morning at the beginning of the day of all testing sessions. Participants removed shoes, socks and heavy outdoor clothing. Height was measured to the nearest 0.1 cm using Seca Portable stadiometer 213 (Medical measuring device, Hamburg, Germany: Seca). Body mass was measured using Marsden floor scale (Weighing Group M-430 , Oxfordshire, UK) to the nearest 0.01 kg. Body mass index (BMI) was calculated to determine weight status (weight kg/ height m^2). Z-score was derived from UK90 cut-offs and weight status defined as typical weight (TW; BMI Z-score < 1.04), or overweight and obesity (OWB; BMI Z-score >1.04; Cole et al 1995).

2.1.1 Air displacement plethysmography assessment of body composition

The use of air displacement plethysmography (ADP) as a body composition measurement tool is relative only to Chapter 4. A detailed explanation of ADP body composition assessment, as well as its validity and reliability in children with OWB, has been discussed in 1.1.4.1. Body fat percentage was calculated from corrected age- and gender-specific equations using body volume and density (Lohman, 1989). Body volume was measured using air displacement plethysmograph (BOD POD, Life Measurement, Inc, Concord, CA, USA). System calibration, according to manufacturer guidelines, was completed before each trial. All children wore tight swimwear and a swimming cap. Two body volume measurements were taken. If these first and second measurements were inconsistent (over 5% difference), a third measurement was taken, and the two closest volume values were used for further analysis. Raw body volume was corrected for isothermal air in the lungs and skin surface (equation 2-1; Haycock et al., 1978). Thoracic gas volume (TGV) were estimated (equations 2-2 and 2-3) from gender and child-specific equations (Fields et al., 2004). Body fat was then estimated using equation 4. Body density constant was calculated from the corrected body volume divided by body mass, constants K_1 and K_2 are age and gender-specific (Lohman, 1989).

Equation 2-1) $Skin\ Surface\ Area = (0.024265BM0.5378)(H0.3964)100$

Equation 2-2) $Thoraic\ Gas\ Volume\ (Boys) = 0.00056H2 - 0.12442H + 8.15194$

Equation 2-3) $Thoraic\ Gas\ Volume\ (Girls) = 0.00044H2 - 0.09220H + 6.00305$

Equation 2-4) $\%FM = 100\ ((K1/Db) - K2)$

BM= body mass (kg), D=Body density, H = height (cm), K = age and gender constant

2.1.2 Bioelectrical impedance assessment of body composition

The use of bioelectrical impedance assessment (BIA) as a body composition measurement tool is relative only to Chapter 6. Due to equipment malfunction, it was not possible to continue the use of the BodPod for body composition estimation without significant cost and time demands. Moreover, the BodPod is not portable and commonly unavailable within clinical settings; therefore, the decision was made to use BIA to estimate body composition in participants in Chapter 6. As discussed in Section 1.1.4.3 ADP and BIA should not be directly compared and are not interchangeable. However, body composition changes are not a primary outcome of the designed intervention studies, and thesis does not set out to draw direct comparison between these.

A detailed explanation of BIA body composition assessment, as well as its validity and reliability in children with OWB, has been discussed in 1.1.4.2. All BIA measurements were taken in the morning at the beginning of each testing day to limit the effect of food and fluid consumed during the day. Bodystat 1500 bioelectrical impedance analyser (Bodystat Ltd., Douglas, Isle of Man) was used with Bodystat electrodes placed on the back of right hand (behind the 3rd finger and on the wrist next to ulna head) and on the top of foot (behind the 3rd toe and ankle in line with and between the medial and lateral malleoli) >5cm apart, as per manufacturer instructions. The same assessor placed the electrodes at each testing point. Participants lay supine for 5mins before measurements were taken. During measurement, participants kept their arms and legs abducted at approximately 45°. Three measurements were taken, and an average impedance (within 10%; if above this threshold, an additional measurement was taken) was taken to calculate fat-free mass (FFMkg). Calculation of FFMkg was performed using chid specific equation (Equation 2-5; Clasey et al., 2011). Fat mass percentage (FM%) was calculated by minus estimated FFMkg from total measured body mass and corresponding FFM% and FM% calculated from total body mass.

Equation 2-5) $FFMkg = (-7{,}655 + 297\, x\, (Height\, [cm]) + 125\, x\, (body\, mass\, [kg]) - 17.4\, x\, impedance/1{,}000$

2.2 Physical well-being

2.2.1 Pain

Participants' pain was evaluated by the PedsQL Paediatric Pain Questionnaire (Appendix A), which was previously discussed in Section 1.2.2. Current pain and worst pain in the last seven days were scored separately on a 10cm visual analogue scale (ranging from not hurting, no discomfort, no pain at one end to hurting a lot, very uncomfortable, severe pain) and measured to the nearest 0.1cm. The questionnaire also asked participants to record where they feel pain in their body and what intensity. Where this pain was described as something other than related to musculoskeletal (MSK) pain (i.e. they had a headache), these were omitted from any further analysis.

2.2.2 Physical health related quality of life

Physical HRQoL was evaluated by PedsQL Pediatric Quality of Life Inventory 4.0 [Health and Activity section only] (Appendix B) and has been previously discussed in Section 1.2.3. Participants were encouraged to ask for clarity around the questions being asked and were supported in reading and understanding items by teachers or guardians present. Items on the PedsQL health and activities section were reverse scored (0=100, 1=75, 2=50, 3=25, 4=0) so that higher scores indicate better quality of life (Varni et al., 2001). An average of all eight questions was taken for the overall HRQoL Score.

2.2.3 Physical activity

PA was monitored using tri-axial accelerometers (ActiGraph model wGT3X-BT, ActiGraph LLC, Florida, USA) data were collected at 80Hz. It should be noted that sampling frequencies outside the default 30Hz may introduce errors resulting in greater counts during higher-intensity movements (Brønd and Arvidsson, 2016). Therefore, total counts should be interpreted with caution. However, when activity intensity thresholds are applied to hip-worn data children, the difference is negligible (Clevenger et al., 2019). Moreover, a trade-off between higher sampling frequencies (for accuracy of capturing movement) and battery life must be struck. According to manufacturer guidelines, with a sampling frequency of 80Hz, battery life may last 13 days, which when accounting for use and age of devices may be reduced (60-80% compared to new device), therefore, 80Hz ensured the highest frequency with sufficient battery life to acquire 7 days of activity.

Participants were told to wear the accelerometers on their right hip (at the waist in line with the right axilla) for seven days, removing only for sleep, swimming, bathing or other water activities and put back on each morning. Parents were also provided with instruction letters on how the device should be worn and when to return to the researcher. Data were extracted using Actlife 6 (ActiGraph LLC, Florida, USA) and analysed in 60s epochs. One day's wear was defined as a wear time of at least 10 hours. Non-wear time was defined as periods of $\geq$20 minutes of zero counts (Cain et al., 2013). Two valid weekdays and one valid weekend day were taken for analysis. PA intensity levels were defined by (Evenson et al., 2008) thresholds and applied to the 60s epochs in the Actilife software. Data extracted was the sedentary time %, moderate to vigorous physical activity % (MVPA%) and total counts (details of these cutoff points can be found in Table 1-4). As stated in Section 1.2.4, the use of 60s epochs may mean that shorter bouts of higher-intensity activity become averaged out, thus reducing the apparent activity level. However, comparisons across time points will be subject to the same limitation.

2.3 Physical function

2.3.1 Clinical physical function

A detailed discussion of clinical physical function tests and the reliability of these measures can be found in Section 1.3.4. The same assessor conducted clinical measures of physical function throughout the experimental chapters. The six minute timed walk (6MTW) consisted of participants walking the length of the laboratory (20m) for 6 minutes, walking around cones at each end. Participants were told to walk as far as they could in the time without running and were notified of the time remaining throughout (Morinder, 2009). At the end of 6 minutes, participants were told to freeze on the spot, and the distance to the back heel was measured to the nearest 1cm.

Single leg stance (SLS) required participants to stand on their stance leg (non-stance leg knee flexed at 90°) with hands on the hips, and knees together. Participants practised the correct position once before being given a rest and the test beginning. Time was stopped when the non-stance foot touched the floor, arms spread out to get balance, or there were large movements on the standing leg (De Kegel et al., 2011). SLS was performed in eyes open conditions first, followed by a rest and then the eyes closed conditions.

Timed-up-and-go (TUG) performance involved recording the time it took participants to go from a seated position, to walk 3m then turn, walk and return to sitting (Williams et al., 2005). A height-adjustable stool with no arms was used and adjusted so participants' knees were bent 90° with feet flat on the ground. Participants were told 'go', and timing began when the participant left the seat and stopped when participants were seated in order to measure "movement time" only (Williams et al., 2005). Three repetitions were recorded, and an average of the three times was used for analysis.

Sit-to-stand (STS) repetitions were counted over one minute, in a standardised position of knee flexed 90° at sitting (using adjustable stool) and arms crossed over the chest (Nunez-Gaunaurd et al., 2013). Participants were told to stand up (full lower limb extension) and sit down (body weight on the seat) as many times as they could for one minute. Total repetitions were recorded.

2.3.2 Strength assessment

Isokinetic strength of the lower limb muscles was measured using isokinetic dynamometry (Cybex II, CSMI, Saughton, USA). Due to the novelty of isokinetic testing, children may exhibit a learning effect (Jones & Stratton, 2000), therefore participants performed familiarisation trials prior to data collection. Collado-Mateo et al. (2020) provided obese children with practice sets before completing a test and a retest within the same session and found excellent reliability between test and retest intraclass correlation coefficient (ICC 0.908-0.975). Warm-up and familiarisation trials were completed within each testing session, consisting of ramped-up effort of concentric contraction until consistent (within 10%) maximal effort results were obtained. The manufacturer assigned positional set-up was used and then adjusted for each participant to ensure alignment of the joint axis. Stabilisation straps were placed over limbs and pelvis to reduce unwanted movement. A summary of the isokinetic dynamometer set-up position and testing velocity is in Table 2-1. Movements were performed within each participant's range of motion. Participants were given standardised verbal encouragement to push and pull against the lever arm as hard and fast as possible. Participants were given a visual indication of each contraction torque level and told to try and beat it. Each extension and flexion contraction was repeated in sets of three. The raw analogue signal was recorded from each trial at 2000Hz.

Table 2-1 Position and Velocity setup of strength assessment of the ankle, knee, and hip

Muscle groups	Position	Velocity
Ankle dorsiflexion/plantarflexion	Prone	30°/s
Knee flexion/extension	Seated	60°/s
Hip flexion/extension	Supine	60°/s
Hip abduction/adduction	Lying on side	60°/s

Typically, during the assessment of lower limb strength, movement will occur in the vertical plane, and therefore, the weight of the limb adds gravitational torque to torque outputs (Kellis & Baltzopoulos, 1996). The error introduced by the gravitational torque of the limb may be proportionately greater in children due to smaller recorded torque values (Jones & Stratton, 2000). Isokinetic dynamometers typically allow for gravitational correction procedures, either using static or dynamic assessment of the gravitational torque of the limb (Baltzopoulos & Brodie 1989). However, these methods may overestimate gravitational torque due to unaccounted elastic components of joints (Baltzopoulos & Brodie 1989). Furthermore, children find relaxing during passive movement difficult and show high levels of coactivation (Baltzopoulos & Brodie, 1989; Kellis & Baltzopoulos, 1996). Additionally, isokinetic dynamometers such as Cybex and Biodex do not allow for gravity correction to be applied to analogue outputs for external data acquisition (Tsiros et al., 2011). Kellis and Baltzopoulos (1996) provide an anthropometric estimation for gravitational correction that can be applied to data. However, this is only applicable to adults. More research is required to determine the best protocols to correct for the effects of gravitational torque in children. Given, the error introduced by gravitational torque will remain across all time points and strength values will only be compared within subject and not across subjects or muscle groups, gravity correction was not applied.

2.3.2.1 Scaling strength

The relationship between muscle strength and body size is well documented with larger bodies producing greater absolute force (Jaric, 2002). The effect of body size is of particular importance in children, given the rates of growth across ages (Croix et al., 2003). Moreover, with consideration of individuals with OWB, the relationship between strength and body size may be different given the larger FM (which does not contribute to strength) in this population. Ratio standard scaling, which is force or torque divided by body size (i.e. body mass, body mass x leg lengths, height, or other body composition measure, is a simplistic method and relies on the assumption that strength is directly proportional to body size (Folland et al., 2008). Ratio scaling is not effective in adjusting for the influence of size in children due to the non-linear relationship to strength during patterns of growth and development across ages and genders (Croix et al., 2003; Wren & Engsberg, 2007). A more appropriate and widely recommended method for scaling to body size in children is allometric scaling (Folland et al., 2008; Wren & Engsberg, 2007). Allometric models take the logarithm of the strength variable and the logarithmic-transformed body size variables as separate independent variables into a linear regression (Nevill & Holder, 1995). The slope of the regression equation is then applied as a power exponent to the body size variable. The strength variable can then be divided by the body size variable to the power exponent to remove the effect of body size (Folland et al., 2008: Jaric, 2002).

The average Maximum torque from three repetitions was allometrically scaled to body mass and fat-free mass using derived mass exponents (separately for body mass and fat-free mass) applied to a power function(b). Mass exponents were derived from the natural logarithm slope of the relationship of torque and mass variable across all participants. Scaled strength values were then taken forward for data analysis.

2.3.3 3D Gait analysis

Lower limb kinematics and kinetics were captured using a fourteen-camera Vicon Nexus system (Vicon Motion Systems Ltd, Oxford, UK) recording at 200 Hz and two floor-mounted force plates (Kistler 9287CA Force Platform, Kistler Instruments Ltd. Hampshire, UK) recording at 1000Hz. To track foot segments, eleven reflective markers (9 mm) were placed on the skin of the foot of the dominant leg (assessed by asking participants which foot they would use to kick a football) to assess movement in rearfoot, midfoot, and forefoot (Figure 2-1). Two markers were placed on the calcaneus and the head of the second metatarsal of the left foot and used for tracking the contralateral limb. The reflective markers created the foot models based on the modified Istituto Ortopedico Rizzoli (IOR) foot model (Leardini, Benedetti, et al., 2007). A combination of cluster markers and digitised markers were used for the lower limb segments to reduce soft tissue artefact due to larger subcutaneous adipose tissue (Angeloni, Cappozzo, Catani, Leardini, 1993; Lerner et al., 2014). Three rigid cluster markers to track the pelvis, thigh, and shank were strapped to the posterior pelvis, mid-lateral thigh and mid-lateral shank of the dominant leg. Nine virtual markers were created by a spring-activated instrumented pointer device (C-motion.Inc., ON, Canada) to create anatomical landmarks from which the lower limb model was derived (Figure 2-2).

Participants walked barefoot at a natural, self-selected speed and took a minimum of three steps before and after the force plates so as not to capture gait initiation or termination (Miller & Verstraete, 1996). Participants walked consistently up and down the lab, taking rest as required. Approximately 20 recordings were completed or more if needed to obtain the minimum three clean trials (singular whole foot placement on forceplate without the participant aiming for force plate contact). Raw marker trajectories were filtered using Woltring (1986) filter and gaps in marker trajectories, <20 frames, were filled with a spline function. The cluster and virtual markers were used to create the six-degrees-of-freedom lower limb IOR gait model in Visual 3D (Cappozzo et al., 1995). Joint angles for the hip, knee and ankle joints in all three-orthogonal axes were calculated in cardan sequence X,Y,Z and internal joint moments, and powers calculated (Cappozzo et al., 2005). Segment angles were calculated for the calcaneus relative to the shank, the mid-foot relative to the calcaneus and the metatarsals relative to the midfoot in all the orthogonal axes. Kinetic and kinematic outputs were filtered low-pass filtered at 15 Hz with a 2nd order Butterworth filter. Initial contact and toe-off of the dominant limb (stance limb) was defined by a vertical force threshold of 10 N. Initial contact and toe-off of the non-dominant limb (contralateral limb) are defined as the vertical displacement of the calcaneus and first toe marker. Initial contact of the non-dominant limb was defined by the lowest vertical position and acceleration of the calcaneus marker for initial contact and upward vertical position and acceleration peak of the first metatarsal marker for toe-off (Leitch et al., 2011). Gait waveforms were normalised to 101 data points. Data was averaged over three clean trials for each participant. Joint moments and powers from gait were non-dimensionally normalised using body mass, leg length (as calculated as the greater trochanter to the lateral malleolus from Visual 3D models) and gravity as per (Pinzone et al., 2016).

Figure 2-1 Modified IOR foot model marker set.

Note: RFM1= first right metatarsal head; RFM2= second right metatarsal head; RFM5= fifth right metatarsal head; RFB1= first right metatarsal base; RFB2= second right metatarsal base; RFB5= fifth right metatarsal base; RTN= right medial apex of the tuberosity navicular= RPT= right lateral apex of the peroneal tubercle; RST= right sustentaculum tali of calcaneus; RFCC= right calcaneus; RFCC= right calcaneus second marker.

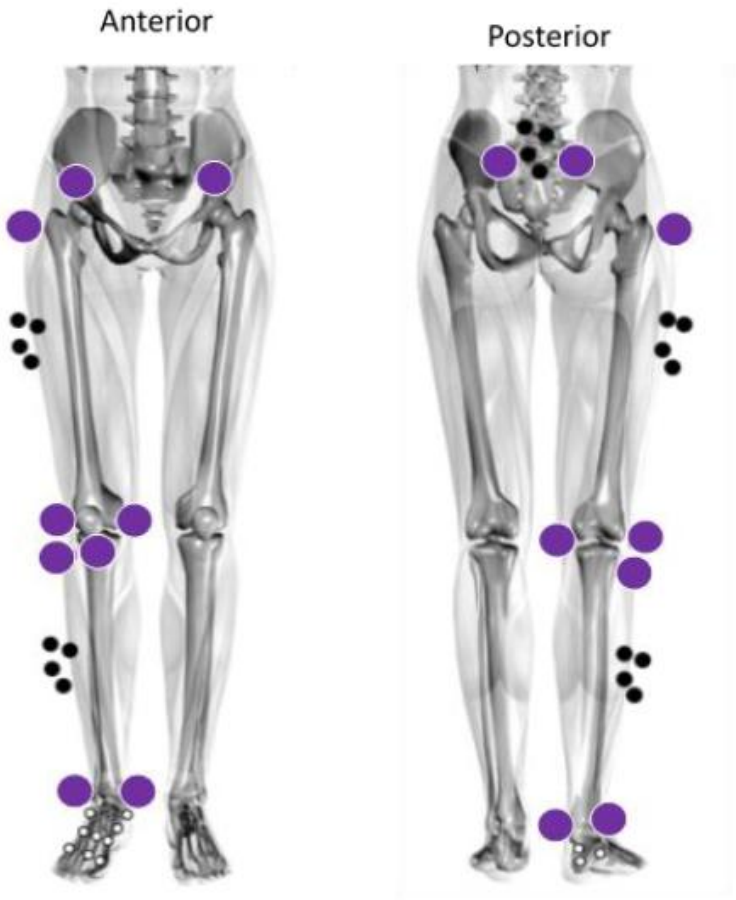

Figure 2-2 Lower limb marker cluster and digital marker set for the lower limb.

Note: ●=cluster marker sets on the pelvis thigh and shank, ● = digitised markers on the anterior and posterior superior iliac spine left and right, greater trochanter, lateral knee, medial knee, head of the femur, tibial tuberosity, medial and lateral malleolus.

2.3.3.1 Temporal-spatial parameters

Temporal spatial measures were calculated for each clean trial and averaged. Stride distance was calculated as the distance from the calcaneus marker at initial contact to the calcaneus marker at the next contact. Gait velocity was calculated as the stride distance divided by the time difference between the first initial contact and the second initial contact. Stance phase was calculated as the time difference between initial contact and toe-off of the dominant limb. Single stance phase was calculated as the time difference between initial contact of the stance of the dominant limb and toe-off of the contralateral limb.

2.3.3.2 Postural Stability during gait

As discussed in Section 1.3.2.4 and 1.3.5, children with OWB may use a combination of ankle and hip strategies during gait; therefore, CoM is used to define postural stability during gait. To reduce time constraints and participant burden, only lower limb markers were used therefore limiting traditional marker-based estimation of CoM. CoM displacement was calculated using a ground reaction force (GRF) model (Buurke et al., 2023) during single stance as previously defined (Section 2.3.3.1). Matlab script “getComGRF” (Buurke, 2022) was applied to GRF data to obtain CoM mediolateral displacement in Matlab 2022b (MathWorks, 2022).

3 Reliability of physical function measures in overweight and obese children.

3.1 Abstract

This study aimed to assess the test-retest reliability of laboratory and clinical physical function measures in overweight and obese, and typical weight children and establish minimal detectable change thresholds to evaluate changes from pre- to post-intervention and, follow-up in an intervention study. Eleven overweight and obese and 11 typical weight children completed isokinetic strength assessment for the ankle, hip, and knee, 3D gait analysis, and clinical measures of physical function tests twice, one week apart. Test-retest reliability was assessed using intraclass correlation coefficient, standard error of measurement and minimal detectable change. The overweight and obese group showed higher reliability and less variability than the typical weight group in clinical measures, isokinetic strength, and sagittal and frontal plane joint angles. Gait waveform standard error of measurement values were consistent across the stance phase, with joint moments and power having greater variation observed during stance transitions and deceleration and acceleration periods. This study demonstrates the need for population-specific reliability statistics and minimal detectable change values may used by researchers and clinicians working with overweight and obese children.

3.2 Introduction

Reliability assesses the degree of error with repeated measurement (test-retest) of an instrument. An amount of error exists within any measure, and this error must be determined to interpret changes in outcome measures accurately (Huang et al., 2011). A measure with a high degree of error, in that it is not reliable, is not suitable to measure changes over time (Hopkins, 2000). Error can manifest in two main forms: systematic error, stemming from factors like instrument learning effects, and random error, introducing unpredictable variability unrelated to true change. Therefore, the reliability of outcome measures must be determined to assess their suitability to assess a change in outcome measures from pre- to post-intervention and to interpret change in a meaningful way, consider the sensitivity of outcome measures to actual change beyond random fluctuations (Huang et al., 2011; Jette et al., 2007; Martin et al., 2017). Minimal detectable change (MDC) is the threshold (at a confidence level) for any given measure that indicates change (greater than noise or error) in a measure between time points (Huang et al., 2011; Jette et al., 2007). Understanding the MDC for a specific population and measure is useful for clinical and research settings to determine change from interventions (Martin et al., 2017).

The reliability of clinical physical function measures is discussed earlier (Section 1.3.4), indicating that clinical measures are generally reliable across a range of populations. The six minute timed walk test (6MTW) has shown excellent reliability (intraclass correlation coefficient [ICC] 0.94) in healthy-weight adolescents (Li, 2005) and good reliability (ICC 0.84) in a combined overweight and obesity (OWB) group and typical weight (TW) children and adolescent group (Morinder, 2009). Reychler et al. (2019) demonstrated that the sit-to-stand (STS) test had good reliability (ICC 0.90) in TW 8-18-year-olds but did report a learning effect at the re-test. Similarly, the timed-up-and-go (TUG) has good reliability in TW 3 to 18 year olds (Nicolini-Panisson & Donadio, 2014; Williams et al., 2005). Finally, single-leg stance (SLS) tests demonstrate good reliability (ICC 0.79-0.86) in TW children in both eyes open and eyes closed conditions (Chuadthong et al., 2023; De Kegel et al., 2011).

However, there are notable gaps in reliability and MDC statistics, specifically for paediatric OWB populations. Children with OWB may differ from TW children or adolescent populations in comfort and motivation during physical tests (Burnett et al., 1990; Valerio et al., 2014). It is, therefore, important to determine the test-retest reliability within children with OWB and determine MDC statistics.

Laboratory-based measures such as isokinetic strength assessment and 3D analysis are rigorous and reliable when implemented according to defined protocols. Isokinetic dynamometry demonstrated excellent reliability (ICC 0.96-0.98) for knee extension and flexion in children with OWB (Collado-Mataeo et al., 2020). This is greater than the reliability statistics reported for TW children for isokinetic knee extension and flexion (ICC 0.62-0.83; Deighan et al., 2003; Fagher et al., 2016). The difference between OWB and TW further justifies the need for OWB-specific reliability statistics, and the differences between OWB and TW groups may warrant further examination. No test-retest reliability data is currently available for hip and ankle isokinetic testing in children with OWB. However, sagittal and frontal hip strength reliability has been reported in TW boys (ICC 0.49-0.68; Burnett et al., 1990), and ankle strength has shown good reliability in TW children (Gonosova et al., 2018).

The reliability of 3D gait analysis has been examined in a range of populations. McGinley et al. (2009) reported 3D kinematics to be reliable and state that errors between 2° and 5° are 'reasonable' based on a systematic review of studies from healthy child and adult populations. A study in children with OWB and adolescents reported errors for lower limb kinematics between 1.12° and 3.56° from discrete points in the gait cycle and peak values (Horsak et al., 2017). Leardini, Sawacha, et al. (2007) reported average standard deviation as a measure of variation for joint rotations of a child-specific marker set as between 1.5° and 5.1°. Factors such as increased soft tissue affecting marker placement and movement during 3D gait analysis can impact reliability (Lerner et al., 2014a; Tucker et al., 2015). Additionally, the reliability of CoM measure of postural stability have not been reported for children with OWB during single stance phase of gait. Lab-based measures may be more greatly affected by assessor error, and therefore, the reliability of assessors can be quantified to interpret change in gait following intervention studies.

The aim of this study is, therefore, to determine the test-retest reliability of laboratory-based (isokinetic strength of hip, knee and ankle; 3D gait analysis and centre of mass excursion) and clinical physical function (6MTW, TUG, STS and SLS tests) measures separately in OWB and TW children. Both OWB and TW children are included in the current study to address the lack of test-retest reliability data in OWB populations, whilst the inclusion of TW children provides a comparison point consistent with existing literature. Additionally, MDC will be determined for each measure to use as a threshold for determining a change in outcome measures from pre- to post-intervention and at follow-up. The information regarding the test-retest reliability of these measures will be used to determine how changes in pre- to post-intervention may be interpreted and applied to Chapter 6 to determine the effectiveness of an implemented exercise intervention.

3.3 Methods

3.3.1 Participants and data collection.

Twenty-two 7-to-11-year-old children were recruited from local schools. Participants visited the laboratory twice, with one week between visits. Isokinetic strength, 3D gait, and clinical physical function data were collected and processed as per the protocols outlined in Chapter 2. Data were collected by the same researcher at each time point at the same time of day. Ethical approval was provided by St Mary's University Twickenham (Appendix C), and written informed consent was obtained from all participants and their guardians (Appendix D).

3.3.1 Statistical analysis

Calculation of reliability statistics was performed on all outcome measures: physical function performance, maximal isokinetic strength values, and temporal-spatial variables from gait analysis. Test-retest reliability was calculated using the intraclass correlation coefficient (ICC; 2,1) as per Hopkins (2015). ICC values were interpreted as poor (<0.5), moderate (0.5-0.75), good (0.75 – 0.9) and excellent (>0.9; Koo & Li, 2016). The ICC is a relative measure of reliability and does not quantify the expected error in data present from test to re-test (Weir, 2005). The standard error of measurement (SEM) presents a value in the same units as the measurement, providing an absolute index of reliability. Variability in strength, gait and performance measures across different participant age ranges and weight status may impact the ICC. Therefore, the SEM was calculated with an adjustment to the SEM calculation to not be influenced by ICC as this can be impacted by the between-subjects variability (equation 3-1; Vincent & Weir, 2021; Weir, 2005).

Equation 3-1) $$SEM = \sqrt{\frac{\Sigma(SD\ test,retest)^2}{n}}$$

However, whilst SEM may be used to define the difference needed between two testing sessions to determine a 'real' change in participants outcome measures, each outcome value (from each testing session) contains a true component and an error component. Therefore, simply reviewing if the score from the second test falls within or outside the error of the first measure does not account for the error within the second measure. The minimum detectable difference between scores is considered a 'real' change in participant performance including 95% confidence intervals (Huang et al. 2011); equation 3-2). The level of confidence was set to 95%.

Equation 3-2) $$MDC = Zscore\ level\ of\ confidence\ x\ SEM\ x\ \sqrt{2}$$

The percentage MDC was also calculated to determine true change independent of the units of measurement. MDC% was calculated as MDC divided by the mean of all scores for all participants (Huang et al., 2011). An MDC% <30% was considered acceptable, and <10% was considered excellent as a commonly applied sensitivity threshold in physical function and strength performance tests in clinical populations (Dobson et al., 2017; Huang et al., 2011; Smidt et al., 2002). MDC% values >30% suggest these measures should be interpreted with caution in later studies. A visual examination of data was performed using Bland Altman plots to asses possible systemic trends in data over time and identify any outliers (Bland & Altman, 1986). The difference between the scores of each time point was plotted against the mean of each time point with 95% limits of agreement. The correlation coefficient for the difference between the scores of each time point and the mean of each time point was calculated to determine learning or motivational effects. A correlation coefficient >-0.5 or <0.5 would suggest learning effects or changes in motivation depending on initial test performance (Herbet et al., 2011).

Examination of the reliability of waveforms from 3D gait analysis of the foot and lower limb was performed. An average SEM of the entire waveform was calculated by taking the average root mean square error (Equation 3-1; Vincent & Weir, 2021) of each point of the stance phase (0-100%). MDC was calculated from the mean SEM of the waveform using equation one. Percent MDC was not calculated for gait waveforms as there is no standard mean from waveforms to calculate from.

3.3.2 Sample size calculation

To determine the sample size for a main intervention study, standard deviations and effect sizes for 6MTW distance were entered into equation 3.1 with an error of 5% (alpha error constant 1.96) and a power of 80% (power constant 0.84; Eng, 2003). 6MTW distance was selected as it is has been most rigorously tested for psychometric properties in OWB (Mahaffey, et al., 2016), is applied in several clinical contexts to infer functional capacity (AST, 2002), and related to altered gait biomechanics.

Equation 3.1)

$$\frac{4\sigma 2(Zcrit + Zpwr)^2}{D2}$$

Where σ is the pooled SD, Zcrit is 1.96, Zpwr is 0.84, and D is the MDC.

3.4 Results

Participant characteristics are in Table 3-1. The OWB group consisted of eight children classified as obese and three as overweight, according to the Department of Health classification. Both OWB and TW groups consisted of six females and five males. There were no significant differences between OWB and TW groups for age ($t_{(20)}$ = -1.119, p = 0.27) or height ($t_{(20)}$ = 0.0798, p = 0.3123). Body mass was significantly different between OWB and TW groups ($t_{(20)}$ = 2.7019, p =0.0137). Sample size estimates using 6MTW distance pooled SD and MDC provided a suggested sample size for a main intervention of 16 participants in each group.

Table 3-1 Participant characteristics of overweight and obese and typical weight groups children.

	OWB *n =11*	TW *n = 11*
Age (years)	8.00 ± 1.12	8.00 ± 1.02
Height (m)	1.38 ± 0.08	1.42 ± 0.80
Body mass (kg)	41.53 ± 9.11	32.76 ± 5.73
Weight status	8 Obese, 3 Overweight	11 Typical Weight
BMI Z-score	2.01 ± 0.60	0.19 ± 0.54

Note: BMI = Body mass index, OWB = Overweight and obese, TW = Typical weight.

Table 3-2 Reliability data from various clinical tests of physical function for both overweight and obese and typical weight children.

	Six minute timed walk (m)		Sit to stand (n)		Timed up and go (s)		Single leg stance (s)		Single leg stance: eyes shut (s)	
	OWB	*TW*	*OWB*	*TW*	*OWB*	*TW*	*OWB*	*TW*	*OWB*	*TW*
Test	531.8 ± 52.4	563.6 ± 39.4	32.4 ± 5.3	28.0 ± 5.5	4.9 ± 0.5	4.6 ± 0.6	64.5 ± 53.5	62.0 ± 47.9	9.1 ± 10.3	9.2 ± 8.9
Retest	517.6 ± 47.4	580.6 ± 51.5	32.0 ± 6.1	30.1 ± 8.6	5.1 ± 0.7	4.7 ± 0.9	61.1 ± 62.2	72.6 ± 66.9	10.1 ± 7.5	8.0 ± 10.9
p-value*	0.21	0.31	0.52	0.25	0.31	0.54	0.77	0.54	0.66	0.79
ICC	0.74	0.34	0.93	0.68	0.45	0.68	0.81	0.57	0.72	-0.13
CI_{95} (ICC)	0.32 - 0.92	-0.26 - 0.77	0.79 - 0.98	0.2 - 0.9	-0.92 - 0.85	-0.2 - 0.92	0.42 - 0.94	-0.02 - 0.86	0.23 - 0.92	-0.76 - 0.51
SEM	25.58	37.30	1.55	4.14	0.50	0.55	25.38	37.67	4.77	10.04
MDC	70.90	103.4	4.30	11.50	1.40	1.50	70.30	104.40	13.20	27.80
MDC (%)	13.50	18.10	13.40	39.50	27.50	32.70	112.10	155.10	137.60	323.00

Note: CI_{95} = 95% confidence interval; ICC = intraclass correlation coefficient; MDC = minimal detectable change; OWB = overweight and obese; SEM = standard error of measurement; TW = typical weight; * = *t*-test on test-retest differences

3.4.1 Clinical physical function

Participants with OWB demonstrated higher reliability in physical performance measures than TW participants, as reflected by higher ICC values. In the 6MTW, Participants with OWB showed good reliability (ICC = 0.80) compared to poor reliability in TW participants (ICC = 0.39), with acceptable MDC% values for both groups (OWB: 13.51%, TW: 18.07%). Similarly, STS performance showed excellent reliability for OWB (ICC = 0.94) and moderate reliability for TW (ICC = 0.73), with acceptable MDC% values only for OWB (OWB: 13.35%, TW: 39.51%). However, in the TUG test, Participants with OWB exhibited poorer reliability (ICC = 0.33) compared to moderate reliability in TW participants (ICC = 0.55), with MDC% exceeding acceptable thresholds in both groups. For the SLS tests, OWB showed good reliability for eyes-open (ICC = 0.83) and eyes-closed (ICC = 0.75) conditions, while TW participants exhibited moderate (ICC = 0.60) and poor reliability (ICC = 0.13), respectively. High MDC% values and variability in SLS tests were evident in Bland-Altman plots (Figure 3-1). All correlation coefficients (see Bland Altman plots Figure 3-1) were between -0.5 and 0.5.

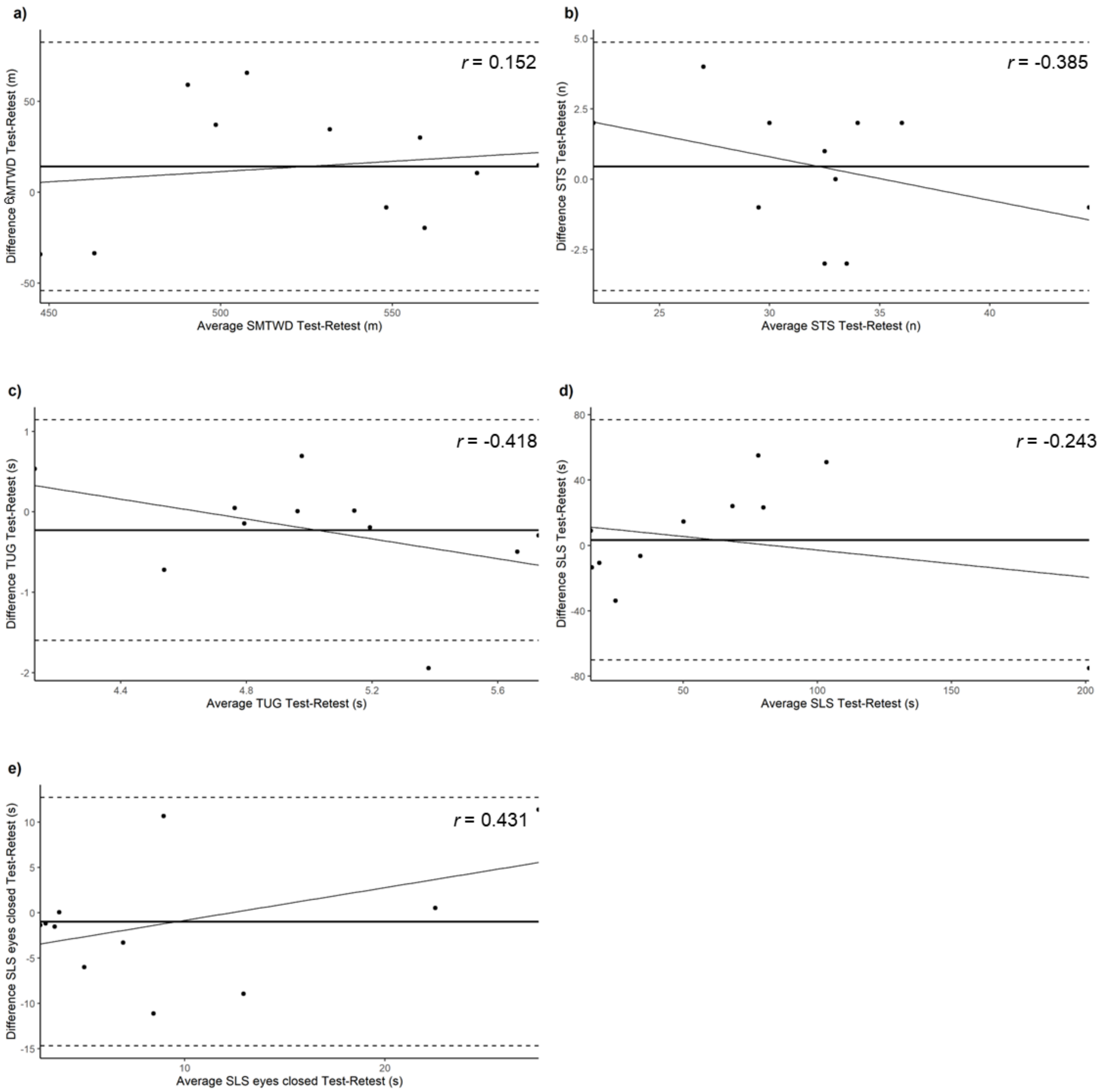

Figure 3-1 Bland Altman plots of OWB clinical physical function measures and correlation coefficient a) 6MTWD (six minute, timed walk distance), b) STS (sit to stand), c) TUG (timed up and go), d) SLS (single leg stance), e) SLS eyes closed (Single leg stance with eyes closed) for the overweight and obese group.

Table 3-3 Reliability data from absolute strength for both overweight and obese and typical weight children

	Ankle Plantarflexion (Nm)		Ankle Dorsiflexion (Nm)		Hip Extension (Nm)		Hip Flexion (Nm)	
	OWB	***TW***	***OWB***	***TW***	***OWB***	***TW***	***OWB***	***TW***
Test	38.43 ± 11.66	34.87 ± 9.43	14.84 ± 3.02	12.8 ± 2.31	72.42 ± 12.39	59.98 ± 15.21	38.61 ± 5.98	36.69 ± 8.45
Retest	38.4 ± 12.17	38.38 ± 11.34	14.52 ± 2.76	12.64 ± 1.85	69.94 ± 14.30	62.14 ± 16.69	37.56 ± 9.62	34.8 ± 8.66
p-value*	*0.981*	*0.269*	*0.192*	*0.613*	*0.347*	*0.116*	*0.612*	*0.719*
ICC	0.96	0.7	0.94	0.79	0.95	0.68	0.86	0.83
CI_{95} (ICC)	0.88 - 0.99	0.41 - 0.93	0.83 - 0.98	0.43 - 0.94	0.84 - 0.99	0.32 - 0.89	0.59 - 0.96	0.57 - 0.94
SEM	2.58	6.4	0.76	1.03	3.89	9.37	3.25	3.84
MDC	4.46	17.74	2.11	2.84	5.47	25.97	9.02	10.64
MDC (%)	17.66	48.4	14.37	22.35	15.15	42.5	23.68	29.89

	Hip Abduction (Nm)		Hip Adduction (Nm)		Knee Extension (Nm)		Knee Flexion (Nm)	
	OWB	***TW***	***OWB***	***TW***	***OWB***	***TW***	***OWB***	***TW***
Test	43.88 ± 14.24	42.23 ± 12	26.51 ± 5.94	20.68 ± 5.64	38.69 ± 7.98	34.84 ± 10.19	52.58 ± 16.42	52.27 ± 16.9
Retest	46.46 ± 13.73	37.07 ± 8.46	24.74 ± 7.17	21.69 ± 6.04	39.05 ± 7.25	35.68 ± 12.60	51.05 ± 16.39	53.64 ± 9.96
p-value*	*0.383*	*0.772*	*0.522*	*0.356*	*0.163*	*0.355*	*0.189*	*0.68*
ICC	0.86	0.89	0.83	0.94	0.97	0.8	0.98	0.67
CI_{95} (ICC)	0.53 - 0.94	0.53 - 0.98	0.54 - 0.94	0.73 - 0.99	0.89 - 0.99	0.34 - 0.88	0.94 - 0.99	0.28 - 0.87
SEM	5.83	5.63	2.78	1.73	1.55	5.37	2.66	6.59
MDC	6.69	15.62	7.68	4.78	3.45	14.23	7.36	18.26
MDC (%)	35.75	39.38	29.95	22.57	11.02	40.34	14.21	34.49

Note: CI_{95} = 95% confidence interval; ICC = intraclass correlation coefficient; MDC = minimal detectable change; OWB = overweight and obese; SEM = standard error of measurement; TW = typical weight; * = *t*-test on test-retest differences

3.4.2 Muscular Strength

Absolute isokinetic strength showed moderate to good reliability across lower limb joints, with Participants with OWB consistently demonstrating higher reliability than TW participants. For ankle plantarflexion, OWB exhibited excellent reliability (ICC = 0.96, MDC% = 17.66%), while TW showed moderate reliability (ICC = 0.70, MDC% = 48.4%). Similarly, for ankle dorsiflexion, Participants with OWB had excellent reliability (ICC = 0.94) compared to good reliability in TW participants (ICC = 0.79), with acceptable MDC% values for both groups.

In hip extension, Participants with OWB demonstrated excellent reliability (ICC = 0.95, MDC% = 15.15%), whereas TW participants showed moderate reliability (ICC = 0.68) with higher MDC% (42.5%). For hip flexion, both groups exhibited good reliability (OWB: ICC = 0.86, MDC% = 23.68%; TW: ICC = 0.83, MDC% = 29.89%). Hip abduction and adduction displayed good reliability for both groups (ICC = 0.86–0.83), though MDC% for hip abduction exceeded acceptable levels. The correlation coefficient of mean hip flexion and difference between test-retest was greater than the -0.5 to 0.5 threshold (Figure 3-3).

Knee strength measures reflected similar trends: Participants with OWB showed excellent reliability in knee extension (ICC = 0.97, MDC% = 11.02%) and knee flexion (ICC = 0.98, MDC% = 14.21%), while TW participants demonstrated good reliability (knee extension ICC = 0.8, MDC% = 40.34%; knee flexion ICC = 0.67, MDC% = 34.49%). Across all measures, differences between tests remained within 95% limits of agreement.

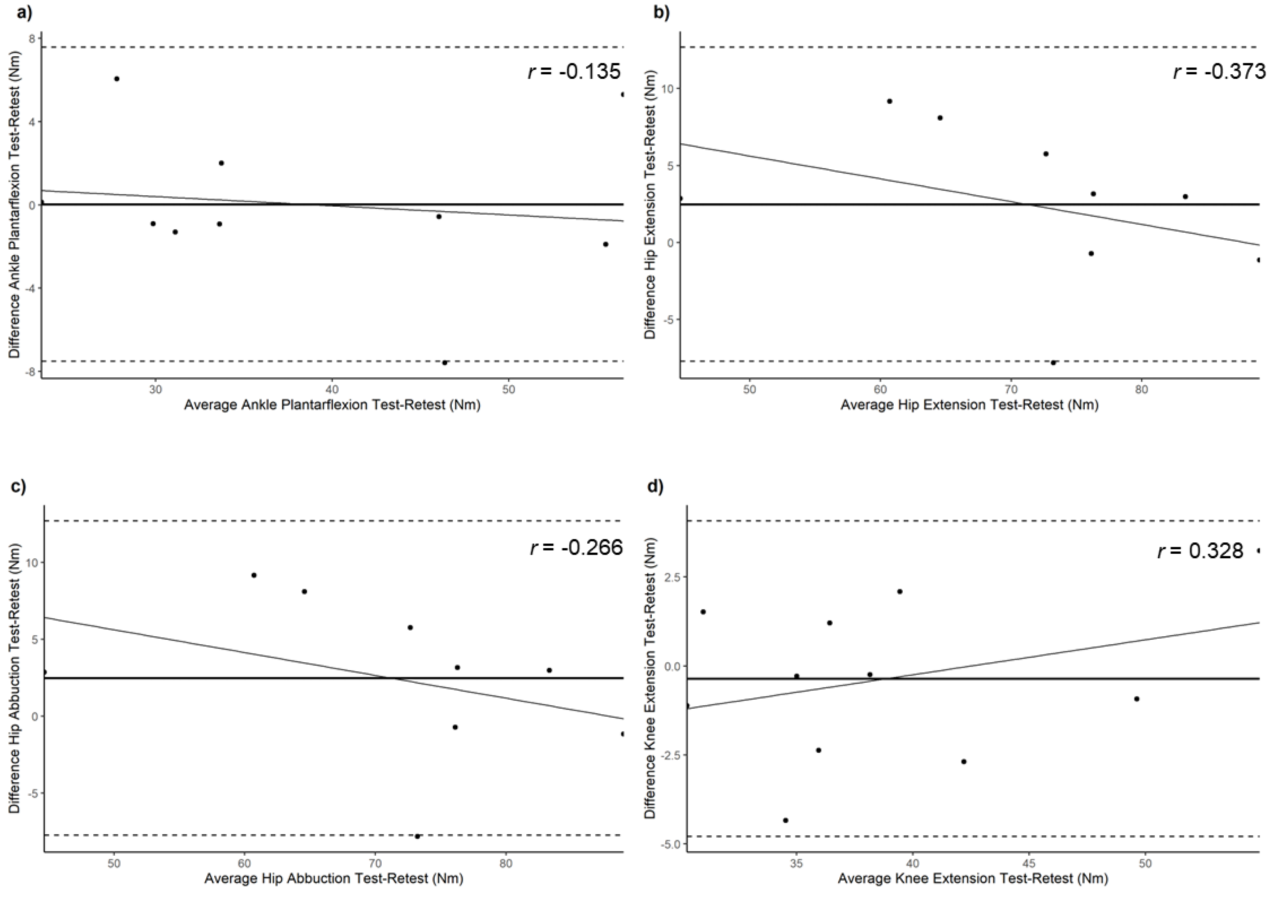

Figure 3-2 Bland Altman plots of absolute strength and correlation coefficient for a) ankle plantarflexion, b) hip extension, c) hip abduction and d) knee extension for the overweight and obese group.

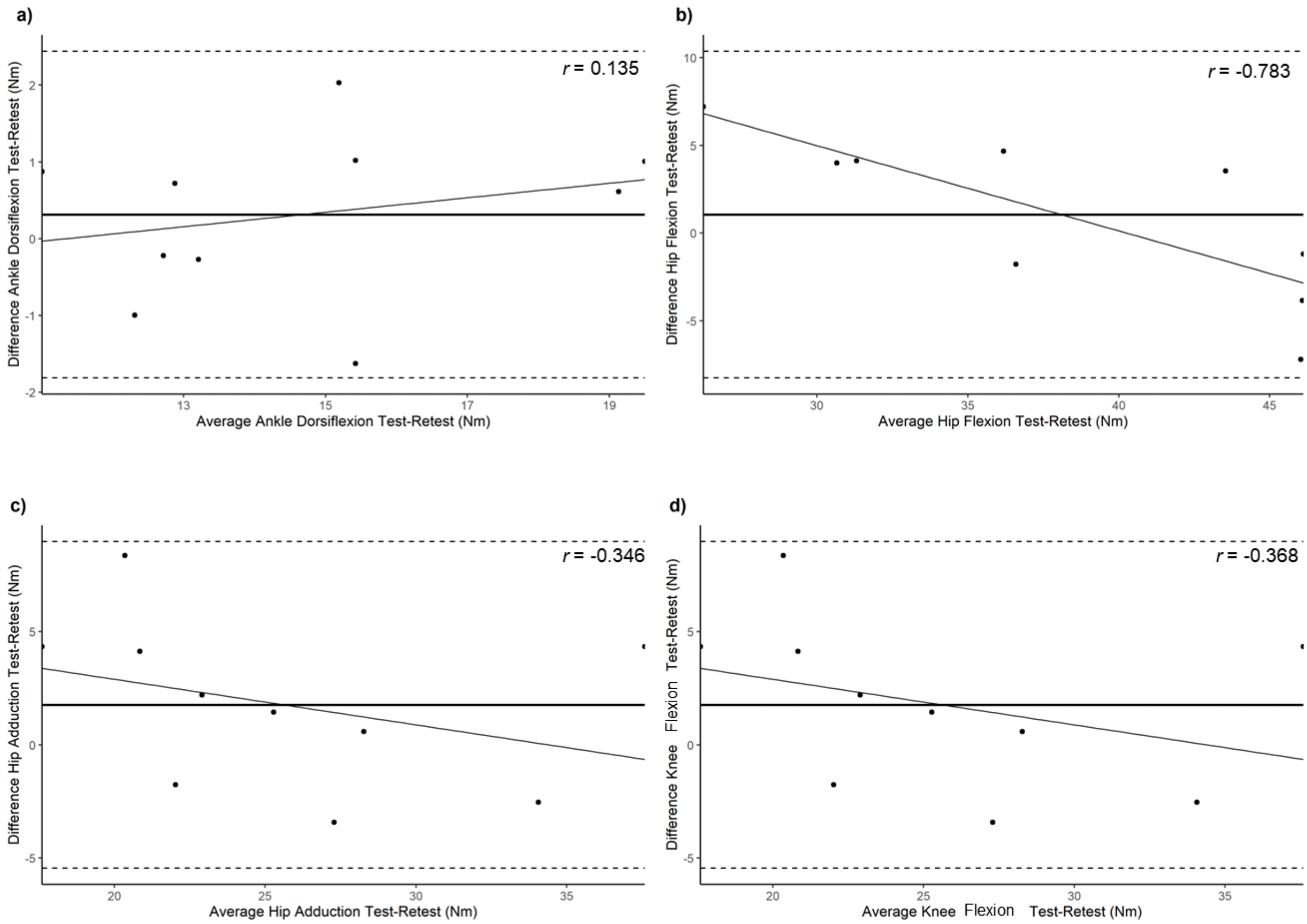

Figure 3-3 Bland Altman plots of absolute strength and correlation coefficient for a) ankle dorsiflexion, b) hip flexion, c) hip adduction and d) knee flexion for the overweight and obese group.

Allometrically scaled isokinetic strength demonstrated moderate to good reliability, with Participants with OWB generally showing higher reliability than TW participants. For allometrically scaled ankle plantarflexion, Participants with OWB exhibited excellent reliability (ICC = 0.96, MDC% = 18.98%), while TW participants showed poorer reliability (ICC = 0.48) and an unacceptable MDC% (44.39%). In allometrically scaled ankle dorsiflexion, Participants with OWB demonstrated good reliability (ICC = 0.90, MDC% = 13.47%), whereas TW participants showed moderate reliability (ICC = 0.73) with a higher MDC% (22.4%).

In allometrically scaled hip extension, Participants with OWB achieved excellent reliability (ICC = 0.94, MDC% = 15.37%), while TW participants exhibited moderate reliability (ICC = 0.51) with a higher MDC% (42.17%). For hip flexion, Participants with OWB showed good reliability (ICC = 0.76, MDC% = 23.84%), and TW participants displayed moderate reliability (ICC = 0.74, MDC% = 30.97%). The correlation coefficient of mean allometrically scaled hip flexion and difference between test-retest was greater than the -0.5 to 0.5 threshold (Figure 3-5). Both groups demonstrated moderate reliability in allometrically scaled hip abduction and adduction, but MDC% values exceeded acceptable thresholds for OWB (36.29% and 35.08%) and TW in hip abduction (36.43%). However, TW showed good reliability in Allometrically scaled hip adduction (ICC = 0.9, MDC% = 26.28%).

For knee strength, Participants with OWB showed excellent reliability in allometrically scaled extension (ICC = 0.92, MDC% = 10.48%) and good reliability in flexion (ICC = 0.89, MDC% = 16.19%). TW participants displayed good reliability in knee extension (ICC = 0.73, MDC% = 39.18%) and moderate reliability in allometrically scaled knee flexion (ICC = 0.62, MDC% = 37.76%). Bland-Altman plots revealed test-retest differences within 95% limits of agreement for all measures except a single outlier in hip extension (Figure 3-4 and 3-5).

Table 3-4 Reliability data from allometrically scaled strength for both overweight and obese and typical weight children

	Ankle Plantarflexion (Nm/BM^b)		Hip Extension (Nm/BM^b)		Hip Abduction (Nm/BM^b)		Knee Extension (Nm/BM^b)	
	OWB	***TW***	***OWB***	***TW***	***OWB***	***TW***	***OWB***	***TW***
Test	5.82 ± 1.77	1.09 ± 0.22	22.1 ± 3.65	3.66 ± 0.77	1.73 ± 0.38	1.22 ± 0.20	3.82 ± 0.5	2.43 ± 0.56
Retest	5.79 ± 1.71	1.19 ± 0.25	21.34 ± 4.16	3.79 ± 0.83	1.82 ± 0.38	1.08 ± 0.18	3.87 ± 0.46	2.49 ± 0.73
p-value*	*0.855*	*0.261*	*0.412*	*0.107*	*0.406*	*0.735*	*0.146*	*0.379*
ICC	0.96	0.48	0.94	0.51	0.67	0.69	0.92	0.73
CI_{95} (ICC)	0.87 - 0.99	-0.85 - 0.18	0.81 - 0.98	0.80 - 0.57	0.23 - 0.88	-0.93 - 0.15	0.79 - 0.97	-0.90 - 0.35
SEM	0.40	0.18	1.20	0.57	0.23	0.15	0.15	0.35
MDC	1.10	0.51	3.34	1.57	0.64	0.42	0.40	0.96
MDC (%)	18.98	44.39	15.37	42.17	36.29	36.43	10.48	39.18

	Ankle Dorsiflexion (Nm/BM^b)		Hip Flexion (Nm/BM^b)		Hip Adduction (Nm/BM^b)		Knee Flexion (Nm/BM^b)	
	OWB	***TW***	***OWB***	***TW***	***OWB***	***TW***	***OWB***	***TW***
Test	1.54 ± 0.21	2.56 ± 0.44	3.55 ± 0.39	2.05 ± 0.36	1.91 ± 0.36	1.34 ± 0.25	0.39 ± 0.06	5.66 ± 1.58
Retest	1.51 ± 0.2	2.52 ± 0.3	3.43 ± 0.68	1.97 ± 0.41	1.76 ± 0.37	1.42 ± 0.34	0.37 ± 0.06	5.81 ± 0.79
p-value*	*0.191*	*0.609*	*0.535*	*0.662*	*0.422*	*0.431*	*0.195*	*0.654*
ICC	0.9	0.73	0.76	0.74	0.70	0.90	0.89	0.62
CI_{95} (ICC)	0.65 - 0.97	-0.91 - 0.21	0.24 - 0.94	-0.90 - 0.22	0.17 - 0.92	-0.98 - 0.13	0.64 - 0.97	-0.85 - 0.78
SEM	0.07	0.21	0.30	0.22	0.23	0.13	0.02	0.78
MDC	0.21	0.57	0.83	0.62	0.64	0.36	0.06	2.16
MDC (%)	13.47	22.4	23.84	30.97	35.08	26.28	16.19	37.76

Note: CI_{95} = 95% confidence interval; ICC = intraclass correlation coefficient; MDC = minimal detectable change; OWB = overweight and obese; SEM = standard error of measurement; TW = typical weight; * = *t*-test on test-retest differences

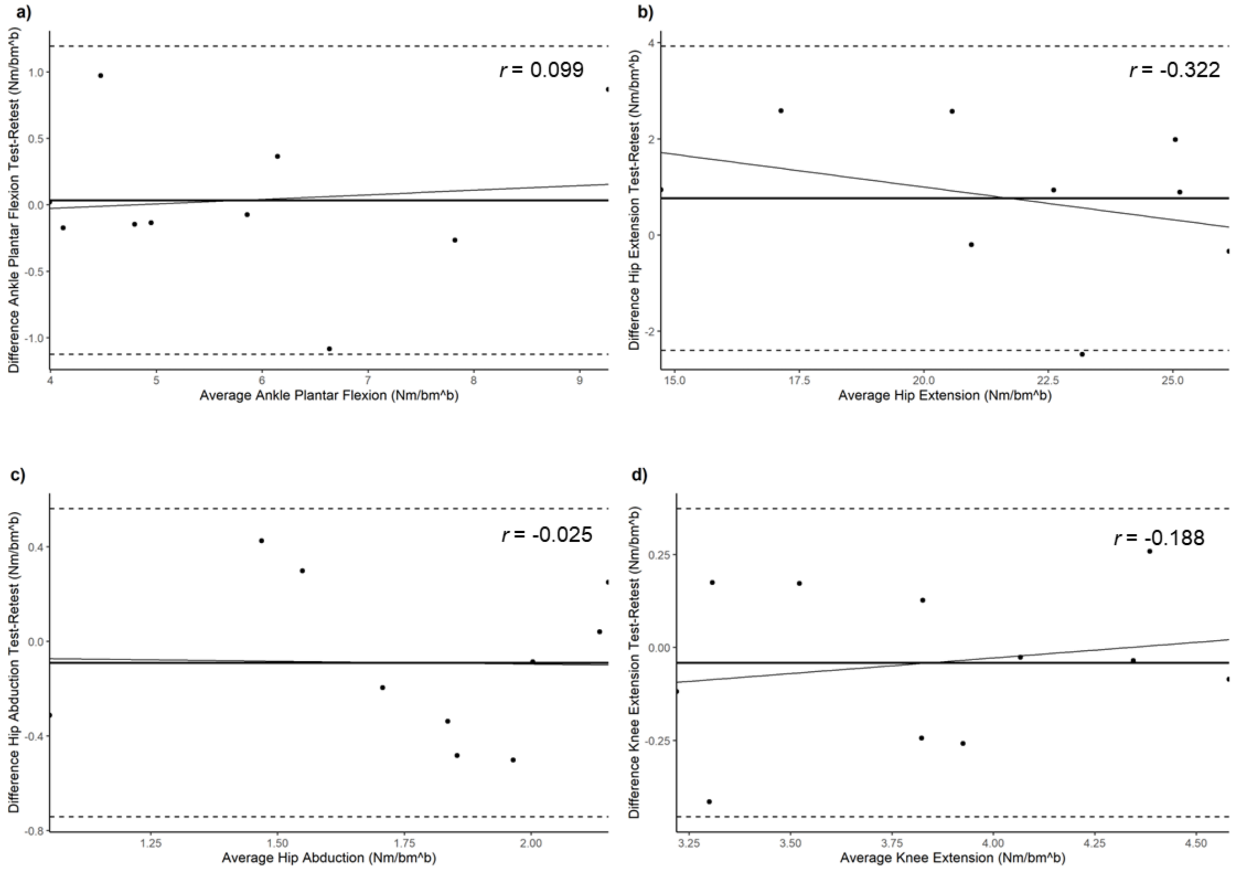

Figure 3-4 Bland Altman plots of allometrically scaled strength and correlation coefficient for a) ankle plantarflexion, b) hip extension, c) hip abduction and d) knee extension for the overweight and obese group.

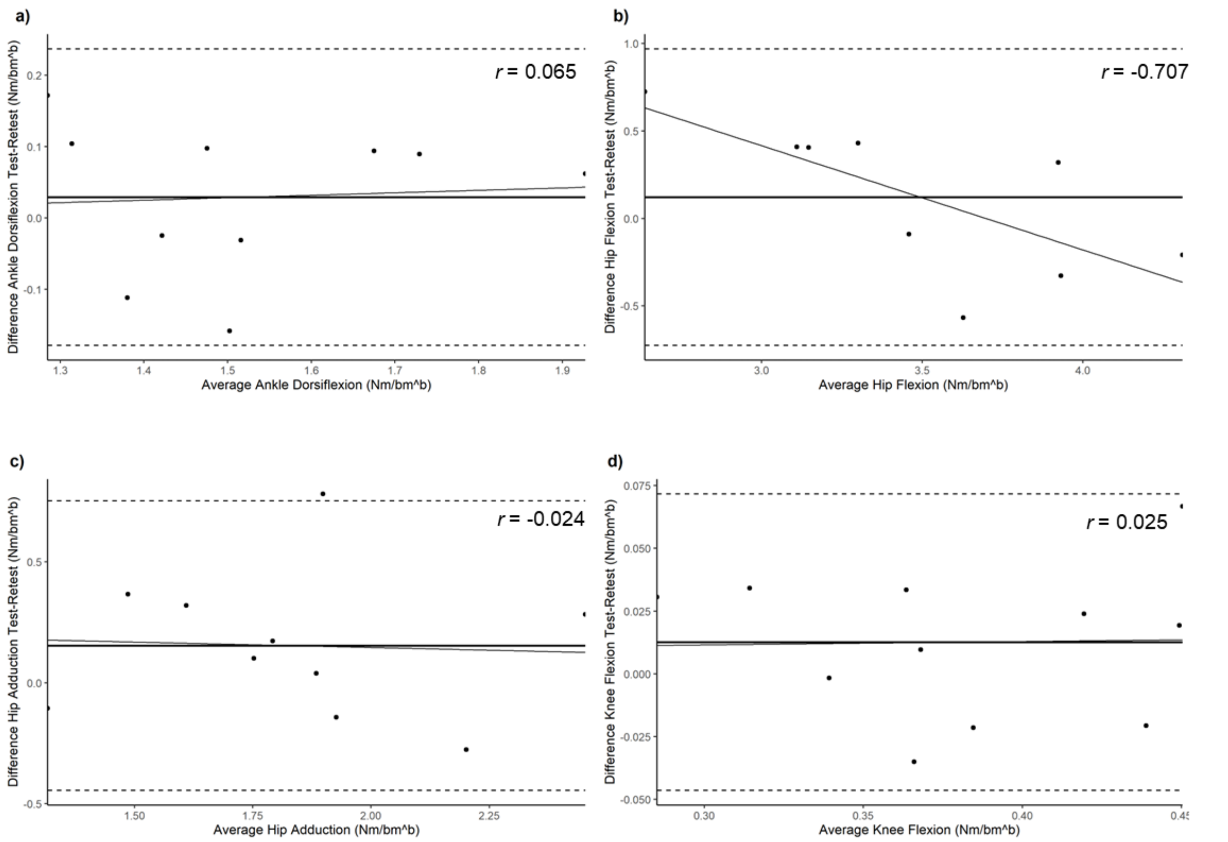

Figure 3-5 Bland Altman plots of allometrically scaled strength and correlation coefficient for a) ankle dorsiflexion, b) hip flexion, c) hip adduction and d) knee flexion for the overweight and obese group.

Table 3-5 Reliability data for temporal-spatial gait parameters for both overweight and obese and typical weight children

	Stride Distance (m)		**Step Width (m)**		**Velocity (m/s)**		**Stance Phase (s)**		**Single support phase (s)**	
	OWB	***TW***	***OWB***	***TW***	***OWB***	***TW***	***OWB***	***TW***	***OWB***	***TW***
Test	1.18 ± 0.12	1.17 ± 0.11	0.13 ± 0.03	0.07 ± 0.02	1.37 ± 0.22	1.31 ± 0.15	0.51 ± 0.06	0.52 ± 0.02	0.36 ± 0.03	0.38 ± 0.02
Retest	1.17 ± 0.09	1.2 ± 0.06	0.12 ± 0.03	0.07 ± 0.04	1.31 ± 0.15	1.37 ± 0.06	0.51 ± 0.05	0.52 ± 0.03	0.38 ± 0.02	0.38 ± 0.03
p-value*	*0.834*	*0.993*	*0.111*	*0.842*	*0.251*	*0.659*	*0.697*	*0.841*	*0.246*	*0.882*
ICC	0.82	0.78	0.56	0.93	0.75	0.47	0.77	0.41	0.62	0.87
CI_{95} (ICC)	0.34 - 0.91	-0.28 - 0.82	0.16 - 0.87	0.31 - 0.94	0.38 - 0.92	-0.08 - 0.88	0.52 - 0.94	0.3 - 0.94	0.38 - 0.91	-0.71 - 0.51
SEM	0.05	0.01	0.02	0.01	0.10	0.07	0.03	0.02	0.02	0.02
MDC	0.13	0.04	0.06	0.652	0.29	0.18	0.82	0.06	0.05	0.06
MDC (%)	11.3	9.19	40.34	23.38	21.51	13.21	16.09	11.05	14.64	6.31

Note : CI_{95} = 95% confidence interval; ICC = intraclass correlation coefficient; MDC = minimal detectable change; OWB = Overweight and obese; TW = Typical weight; SEM = standard error of measurement;, * = *t*-test on test-retest differences

3.4.3 Centre of mass during single stance phase of gait.

The OWB group demonstrated excellent reliability in CoM displacement and velocity measures during single stance phase of gait (Table 3-6). ICC values were also greater than that of the TW group for all CoM measures. Mean mediolateral CoM velocity and SD mediolateral CoM velocity demonstrated MDC% less than 30%. Bland Altman plots revealed no outliers (Figure 3-6)

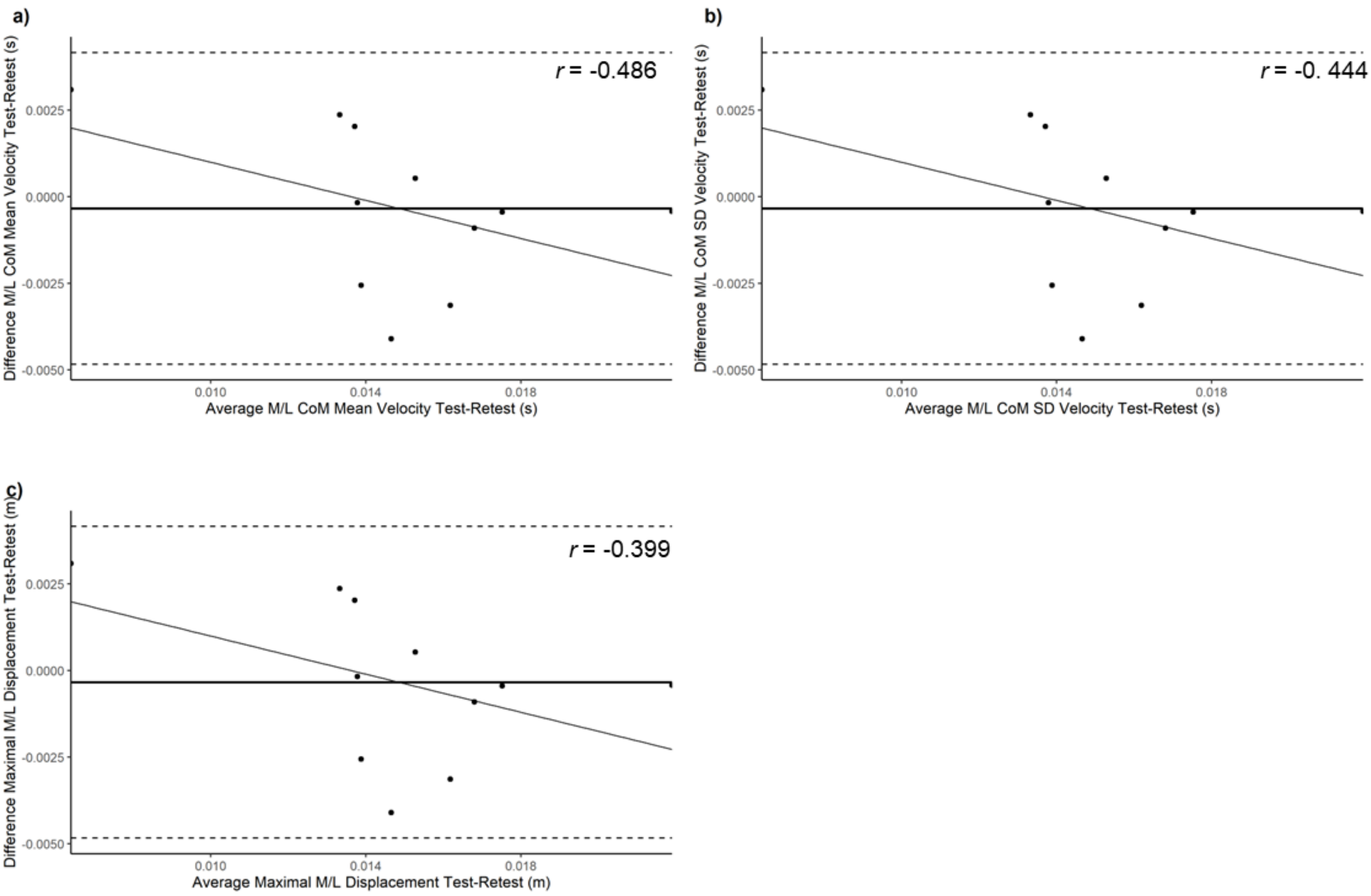

Figure 3-6 Bland Altman plots of centre of mass stability during single stance phase of gait and correlation coefficient for a) Mean velocity, b) standard deviation of velocity, and c) Displacement for the overweight and obese group.

Table 3-6 Reliability data for Mediolateral CoM velocity and displacement for both overweight and obese and typical weight children.

	M/L CoM Mean Velocity		**M/L CoM SD Velocity**		**Maximal M/L Displacement**	
	OWB	***TW***	***OWB***	***TW***	***OWB***	***TW***
Test	0.015 ± 0.004	0.015 ± 0.003	0.011 ± 0.003	0.011 ± 0.002	0.523 ± 0.255	0.484 ± 0.202
Re-test	0.015 ± 0.005	0.016 ± 0.002	0.011 ± 0.004	0.012 ± 0.001	0.529 ± 0.289	0.487 ± 0.126
p-value*	*0.802*	*0.355*	*0.625*	*0.198*	*0.857*	*0.511*
ICC	0.94	0.751	0.93	0.414	0.969	0.963
CI95 (ICC)	0.702-0.988	-0.782 - 0.965	0.677 - 0.987	-3.189 - 0.918	0.844 - 0.994	0.643 - 0.996
SEM	0.001	0.002	0.001	0.001	0.063	0.056
MDC	0.004	0.005	0.003	0.004	0.174	0.156
MDC (%)	26.34	30.88	27.26	32.94	33.13	34.37

Note: CI_{95} = 95% confidence interval; ICC = intraclass correlation coefficient; MDC = minimal detectable change; M/L = mediolateral; CoM = centre of mass; OWB = overweight and obese; SEM = standard error of measurement; TW =Typical weight, * = *t*-test on test-retest differences

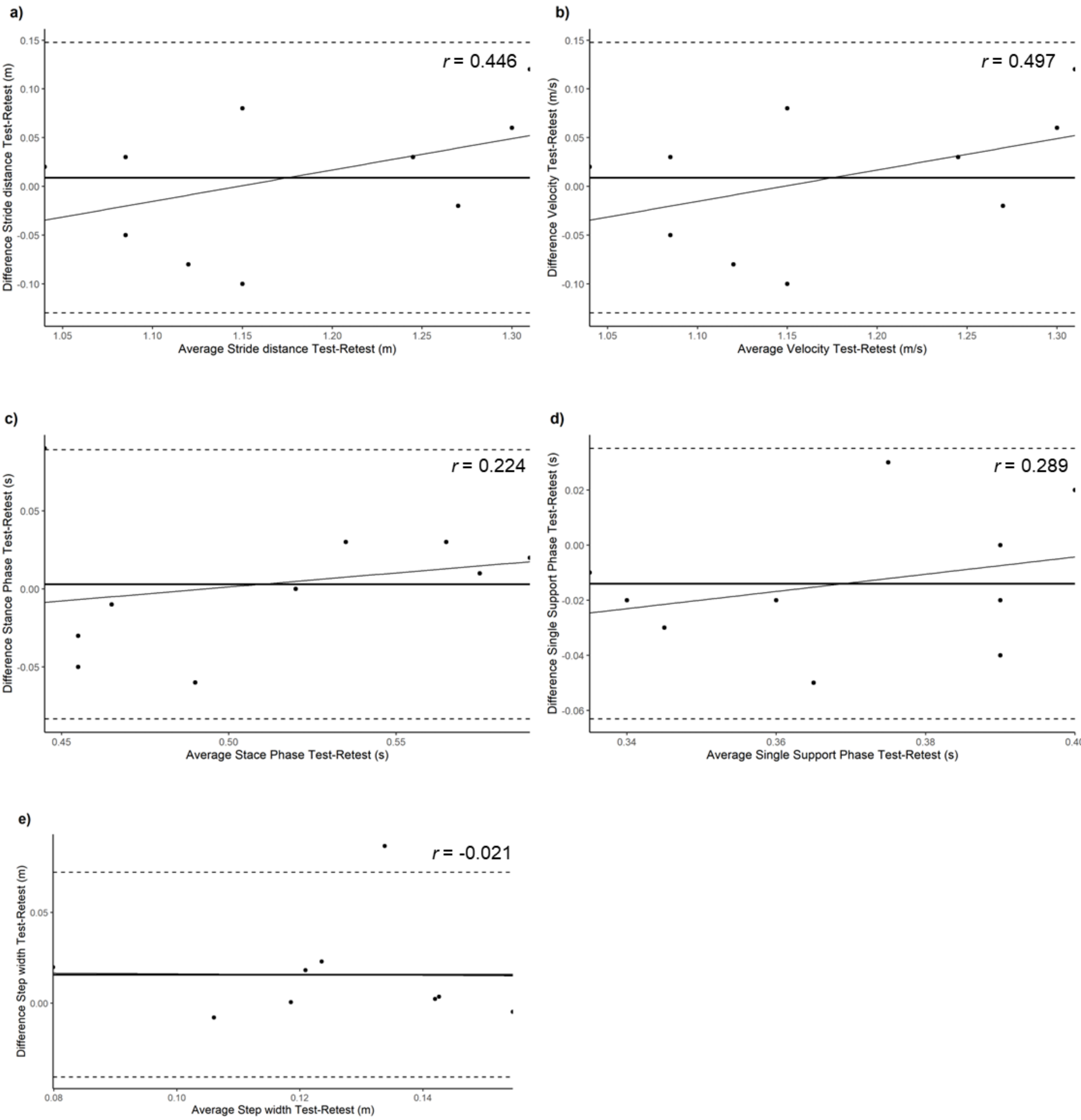

Figure 3-7 Bland Altman plots and correlation coefficient for a) Stride distance, b) gait velocity, c) stance phase time, d) single support time, and e) step width in overweight and obese group

3.4.4 3D foot kinematics

Participants in the OWB group had greater SEM values for all 3D foot kinematics compared to the TW group (Table 3-7). Visually inspecting the stance phase waveforms shows some fluctuations in SEM through the waveform for the shank to calcaneus angle (Figures 3-8). In contrast, calcaneus to midfoot angle SEM values were stable throughout the stance phase.

Table 3-7 Reliability data for 3D foot motion waveforms during stance for both overweight and obese and typical weight children.

		SEM		**SEM Upper 95%CI**		**MDC**	
		OWB	***TW***	***OWB***	***TW***	***OWB***	***TW***
Shank to Calcaneus angle	Frontal	4.59	2.73	5.41	3.22	12.73	7.57
	Transverse	6.52	3.88	7.69	4.57	18.08	10.75
	Sagittal	5.74	2.7	6.77	3.18	15.91	7.47
Calcaneus to Midfoot angle	Frontal	3.81	2.14	4.49	2.52	10.55	5.93
	Transverse	4.85	1.42	5.72	1.67	13.46	3.94
	Sagittal	6.16	2.78	7.26	3.27	17.08	7.7
Midfoot to Metatarsal angle	Frontal	1.88	1.72	2.22	2.02	5.22	4.75
	Transverse	4.78	2.41	5.64	2.84	13.26	6.69
	Sagittal	5.56	2.11	6.56	2.49	15.42	5.85

Note: MDC = minimal detectable change, OWB = Overweight and obese, SEM = standard error of measurement, TW = Typical weight

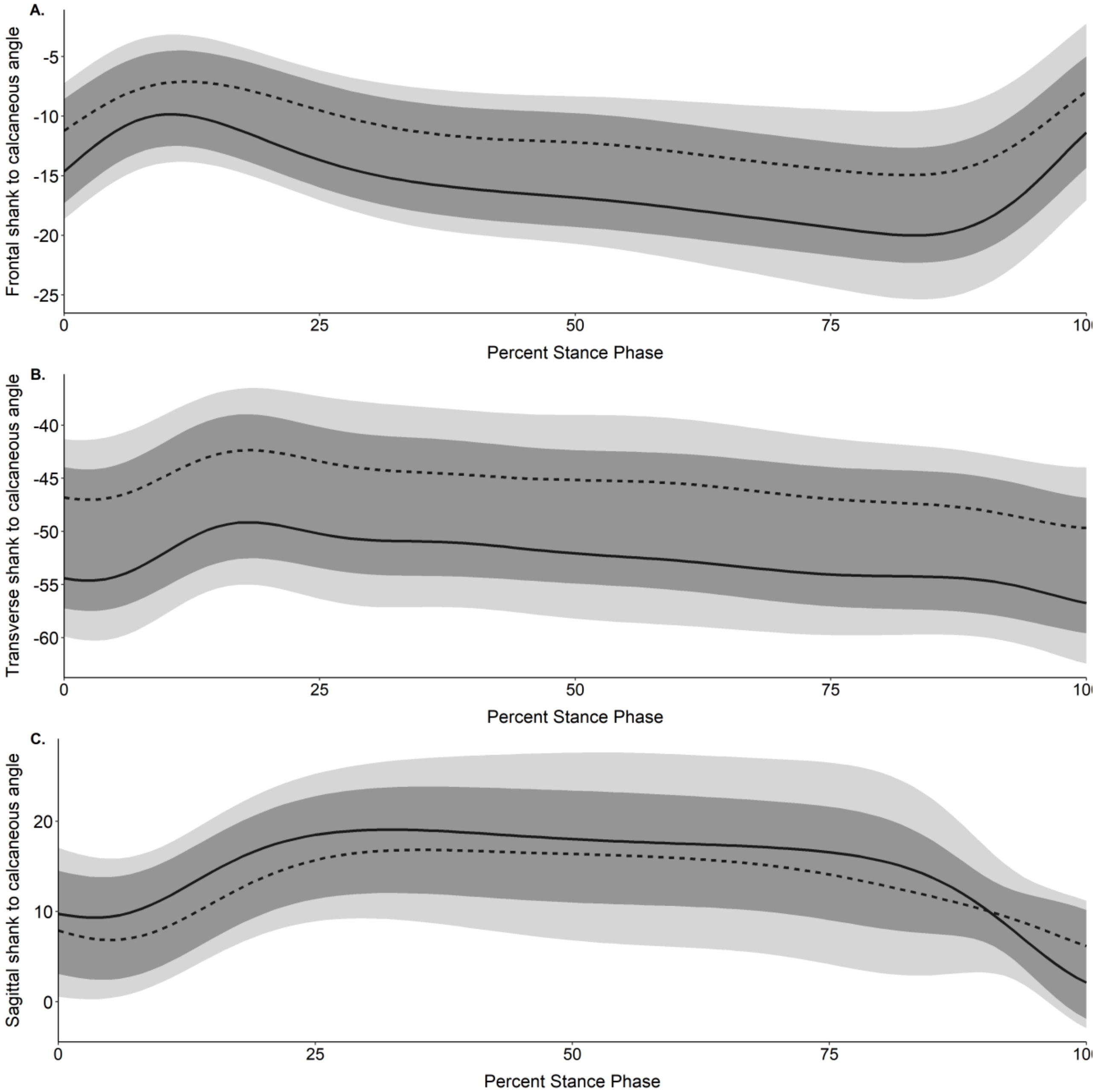

Figure 3-8 Stance phase waveforms of shank to calcaneus angle in the a) frontal plane, b) transverse plane and c) sagittal plane for the overweight and obese group test (solid line) and re-test (dashed line), with corresponding standard deviation (dark grey) and standard error of measurement (light grey) around the test-retest average.

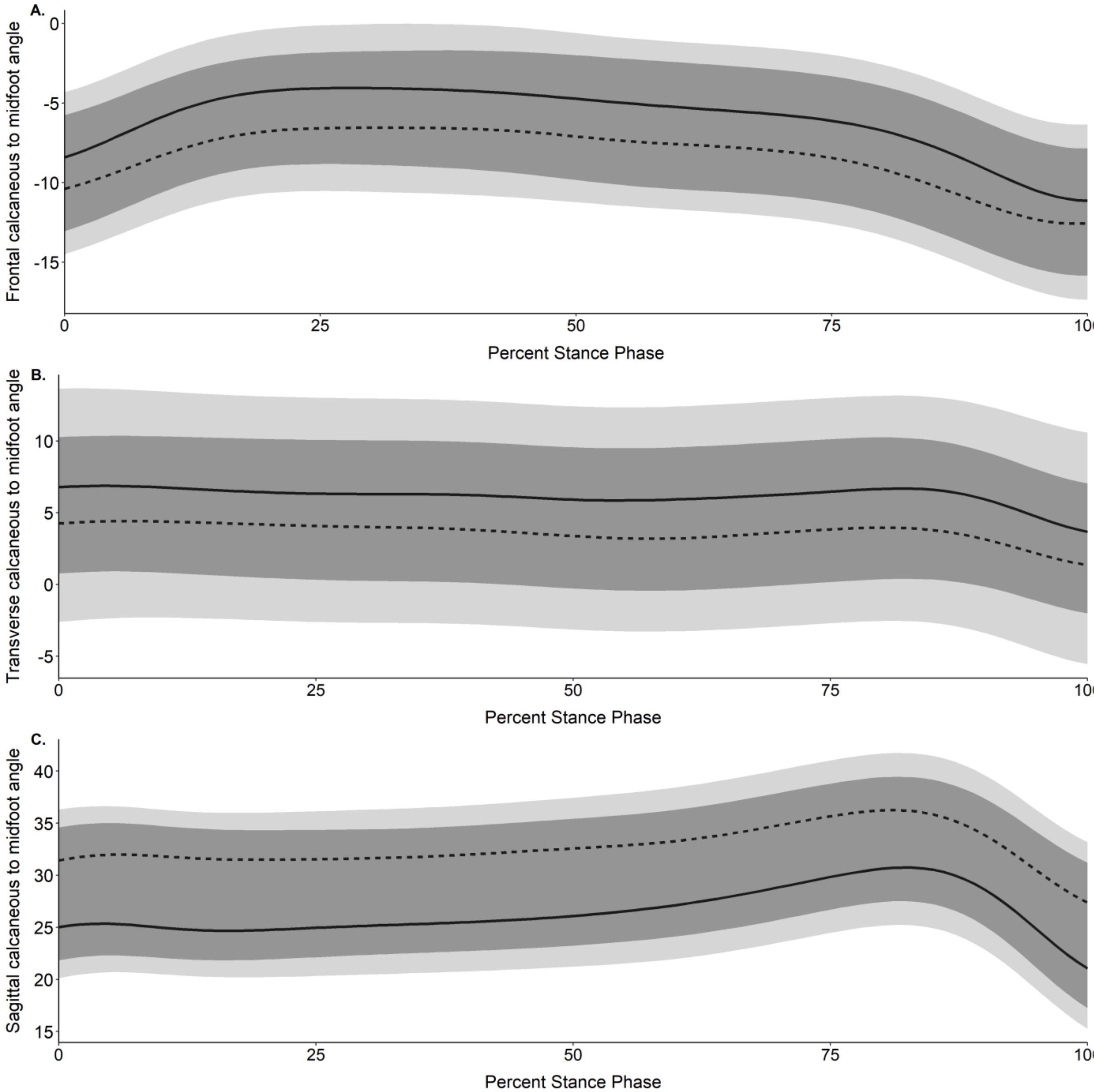

Figure 3-9 Stance phase waveforms of calcaneus to midfoot angle in the a) frontal plane, b) transverse plane and c) sagittal plane for the overweight and obese group test (solid line) and re-test (dashed line), with corresponding standard deviation (dark grey) and standard error of measurement (light grey) around the test-retest average.

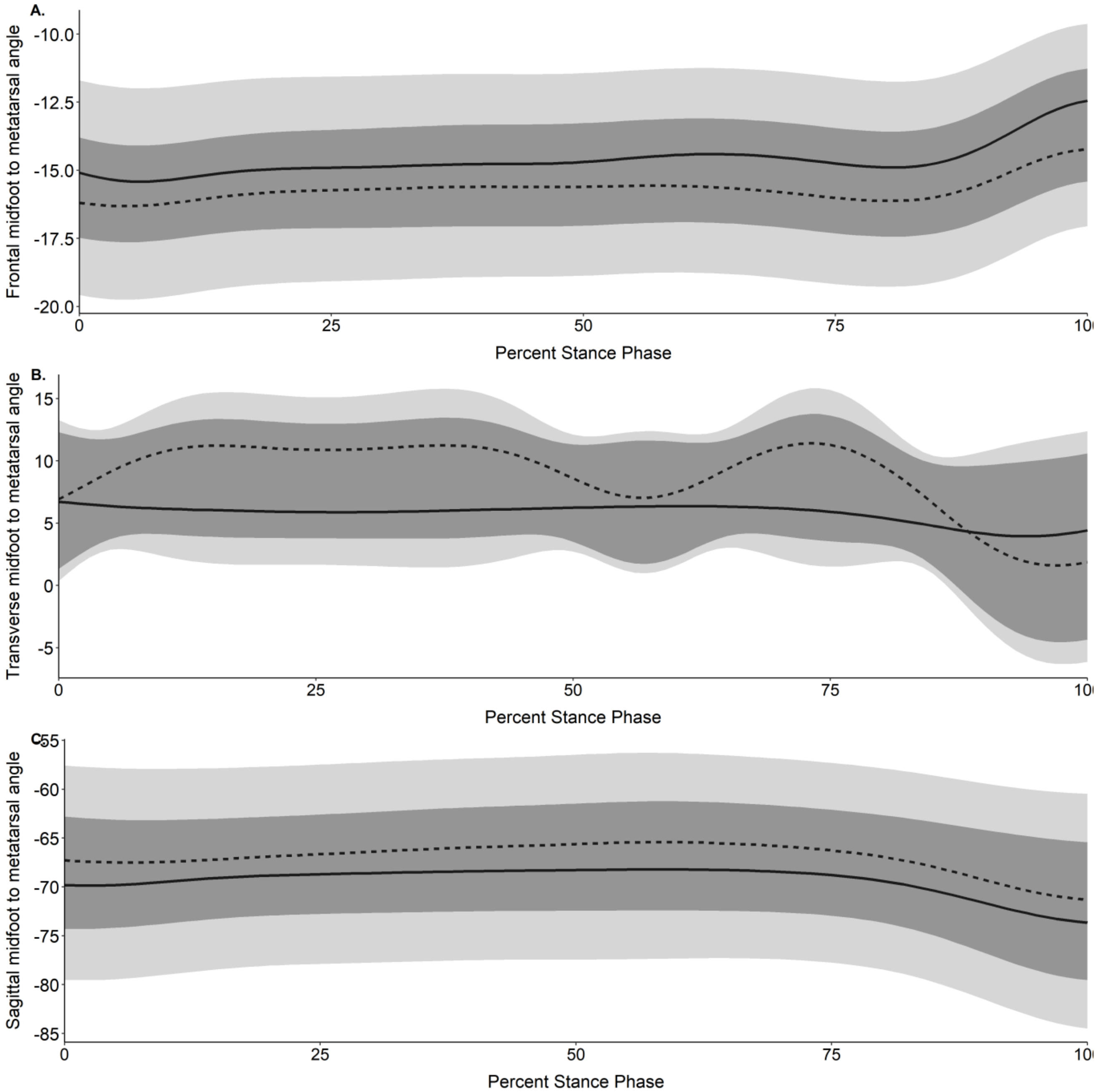

Figure 3-10 Stance phase waveforms of midfoot to metatarsal angle in the a) frontal plane, b) transverse plane and c) sagittal plane for the overweight and obese group test (solid line) and re-test (dashed line), with corresponding standard deviation (dark grey) and standard error of measurement (light grey) around the test-retest average.

3.4.5 3D Lower limb gait kinematics

Frontal and sagittal plane ankle and knee angles and frontal hip angle all had MDC% below the 30% thresholds (Table 3-8). SEM values in the transverse plane were greater in OWB than in the TW group. SEM values for the hip in all three planes, and transverse knee angle exceeded 2-5. SEM values were stable across stance phase waveforms (Figure 3-11 to 3-13).

Table 3-8 Reliability data for 3D lower limb kinematic waveforms during stance for both overweight and obese and typical weight children.

		SEM		**SEM Upper 95%CI**		**MDC**	
		OWB	***TW***	***OWB***	***TW***	***OWB***	***TW***
Ankle Angle	Frontal	2.93	3.61	3.45	4.26	8.12	10.01
	Transverse	11.97	4.69	14.11	5.53	33.18	13.00
	Sagittal	4.58	4.18	5.4	4.92	12.70	11.57
Knee Angle	Frontal	2.70	3.33	3.18	3.92	7.48	9.22
	Transverse	13.14	9.03	15.49	10.65	36.42	25.04
	Sagittal	3.81	6.62	4.49	7.80	10.56	18.35
Hip Angle	Frontal	5.95	5.16	7.01	6.08	16.49	14.30
	Transverse	12.02	8.18	14.17	9.65	33.32	22.68
	Sagittal	12.5	12.09	14.73	14.25	34.65	33.52

Table 3-9 Reliability data for 3D lower limb joint moment waveforms during stance for both overweight and obese and typical weight children.

		SEM		SEM Upper 95%CI		MDC	
		OWB	***TW***	***OWB***	***TW***	***OWB***	***TW***
Ankle Moment	Frontal	0.017	0.016	0.020	0.019	0.05	0.04
	Transverse	0.011	0.012	0.013	0.014	0.03	0.03
	Sagittal	0.02	0.046	0.024	0.054	0.06	0.13
Knee Moment	Frontal	0.014	0.024	0.017	0.028	0.04	0.07
	Transverse	0.009	0.014	0.011	0.017	0.03	0.04
	Sagittal	0.018	0.035	0.021	0.041	0.05	0.10
Hip Moment	Frontal	0.025	0.037	0.030	0.044	0.07	0.10
	Transverse	0.017	0.018	0.020	0.021	0.05	0.05
	Sagittal	0.022	0.039	0.026	0.047	0.06	0.11

Table 3-10 Reliability data for 3D lower limb joint power waveforms during stance for both overweight and obese and typical weight children.

		SEM		SEM Upper 95%CI		MDC	
		OWB	***TW***	***OWB***	***TW***	***OWB***	***TW***
Ankle Power	Frontal	0.004	0.002	0.005	0.003	0.01	0.01
	Transverse	0.003	0.002	0.003	0.003	0.01	0.01
	Sagittal	0.009	0.008	0.010	0.009	0.02	0.02
Knee Power	Frontal	0.003	0.003	0.003	0.004	0.01	0.01
	Transverse	0.003	0.003	0.003	0.003	0.01	0.01
	Sagittal	0.010	0.009	0.011	0.011	0.03	0.03
Hip Power	Frontal	0.010	0.006	0.011	0.007	0.03	0.02
	Transverse	0.007	0.003	0.008	0.004	0.02	0.01
	Sagittal	0.013	0.013	0.015	0.016	0.04	0.04

3.4.6 3D Lower limb gait kinetics.

The OWB group showed lower SEM values for all joint moments except for frontal ankle moment, compared to TW participants (Table 3-9). Visual examination of moment stance phase waveforms indicate increased SEM values around transitions between single and double stance (opposite toe off ~ and opposite toes down) for frontal and transverse ankle moment, frontal and transverse knee moment and transverse and sagittal hip moment (Figure 3-14, 3-15 and, 3-16). OWB groups and TW groups demonstrated a similar pattern of increasing variability in sagittal plane joint moments relative to the transverse and frontal planes for each joint, excluding frontal hip moment for the OWB group, which had greater SEM value than all other joint moment variables for the OWB group (Table 3-9).

For joint power of the ankle, knee and hip during stance, the OWB group showed comparable or marginally greater SEM values than TW participants (Table 3-10). SEM values were greater for joint power in the sagittal plane in both OWB and TW groups relative to the frontal and transverse planes (table 10). Visual examination of waveforms shows the SEM for joint power tended to be greater at the beginning and end of stance phase (during acceleration and deceleration periods), remaining relatively stable during midstance for frontal plane ankle, knee and hip power, and transverse ankle and hip power (Figures 3-17, 3-18 and, 3-19).

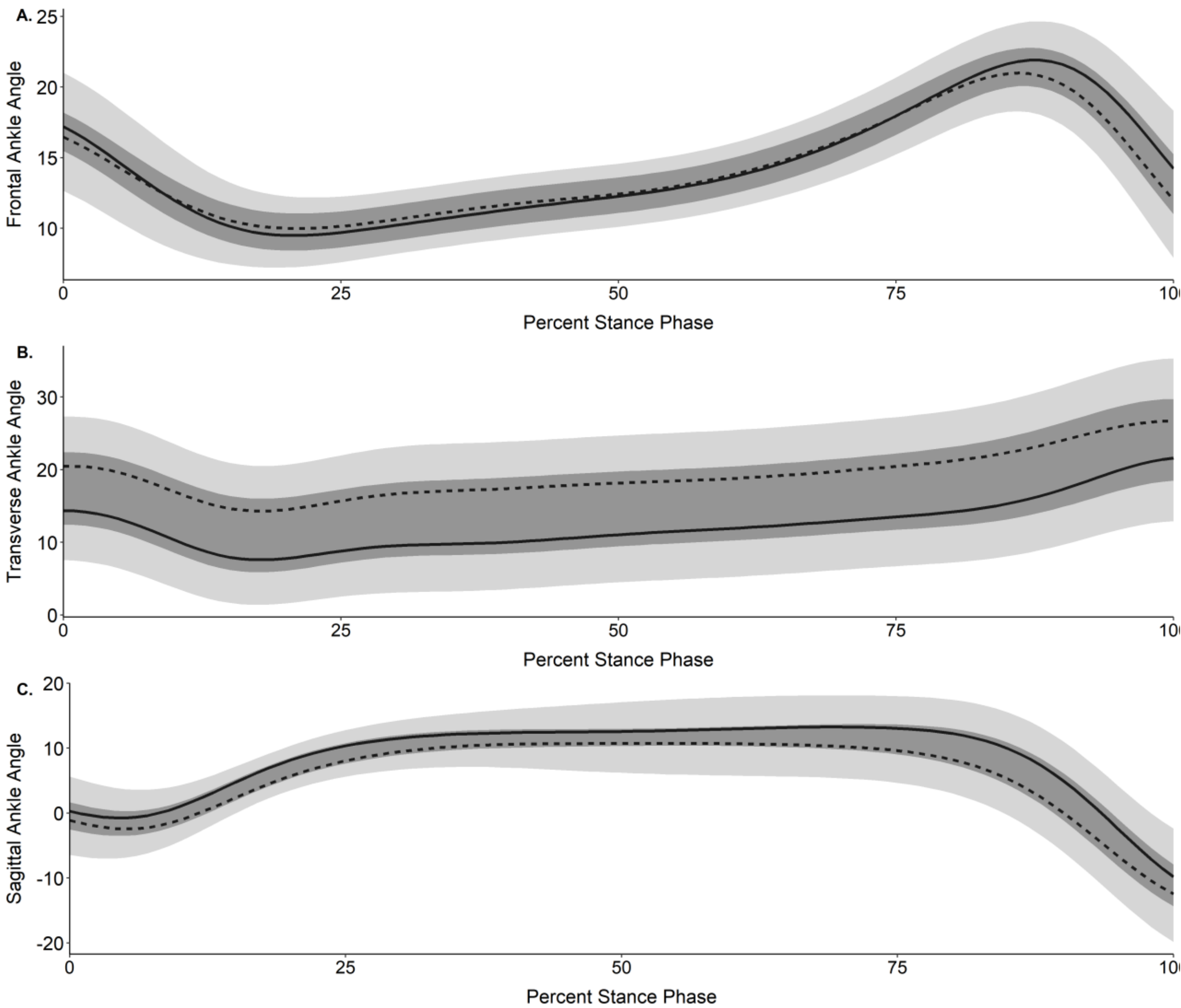

Figure 3-11 Stance phase waveforms of ankle angle in the a) frontal plane, b) transverse plane and c) sagittal plane for the overweight and obese group test (solid line) and re-test (dashed line), with corresponding standard deviation (dark grey) and standard error of measurement (light grey) around the test-retest average.

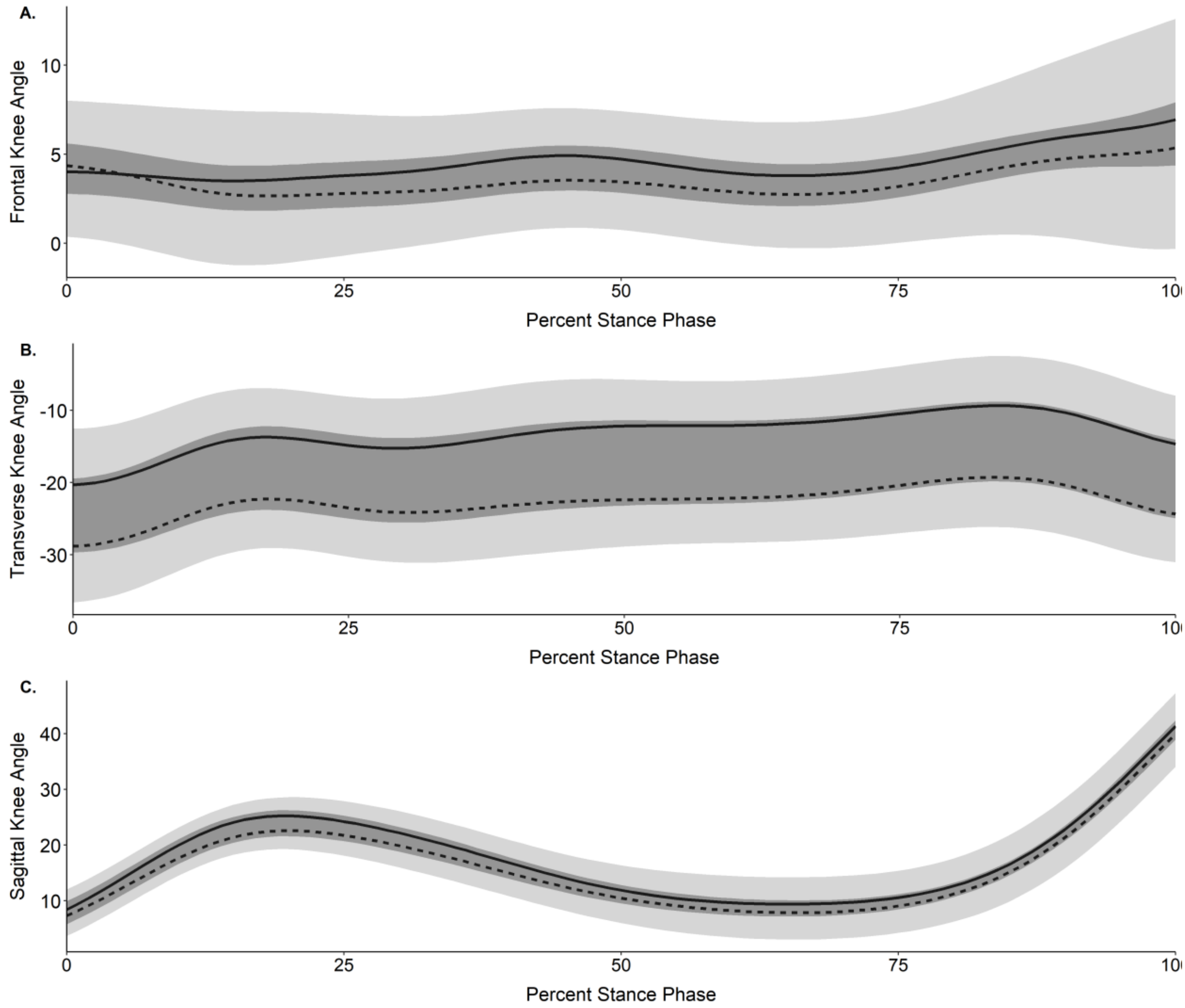

Figure 3-12 Stance phase waveforms of knee angle in the a) frontal plane, b) transverse plane and c) sagittal plane for the overweight and obese group test (solid line) and re-test (dashed line), with corresponding standard deviation (dark grey) and standard error of measurement (light grey) around the test-retest average.

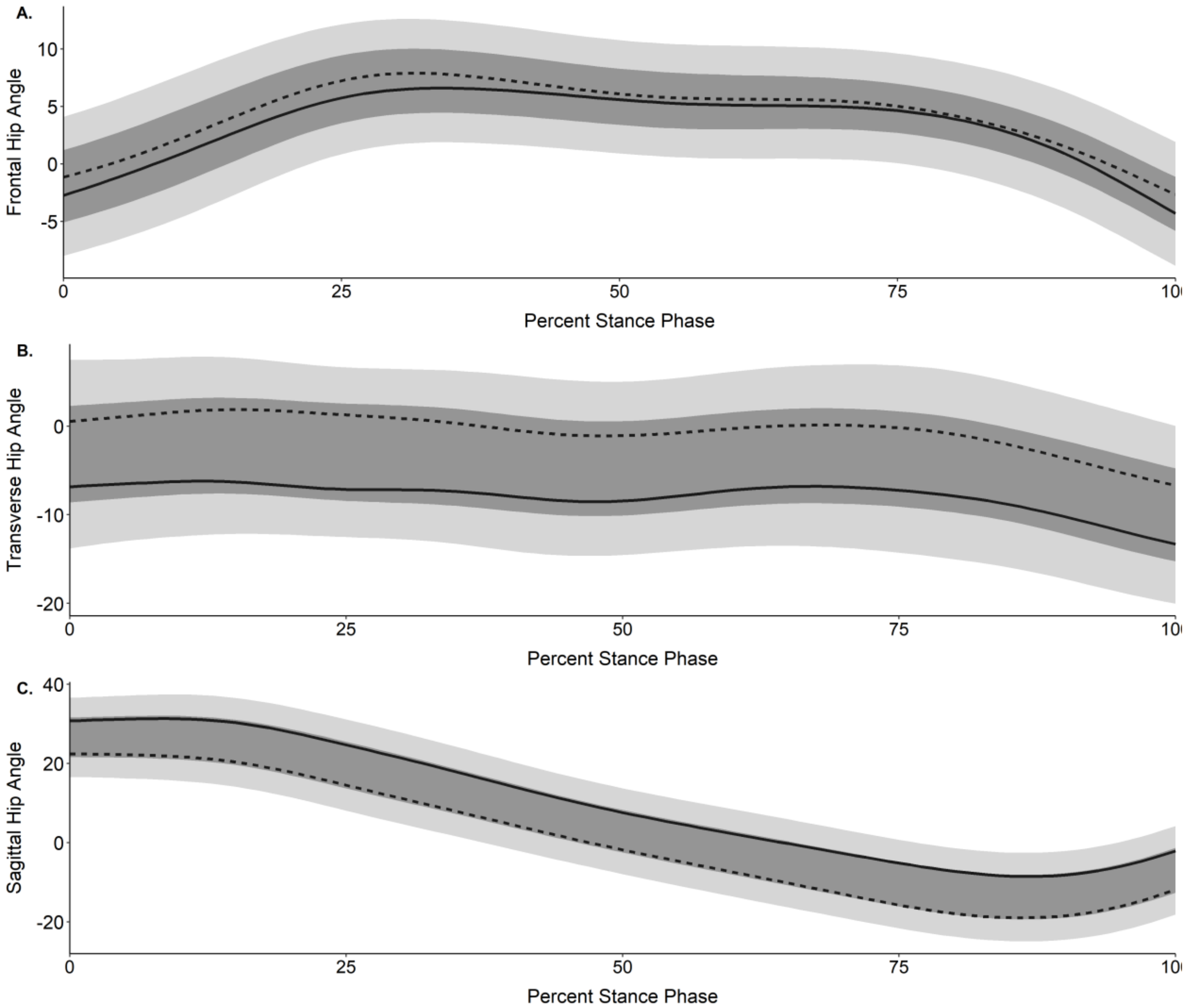

Figure 3-13 Stance phase waveforms of hip angle in the a) frontal plane, b) transverse plane and c) sagittal plane for the overweight and obese group test (solid line) and re-test (dashed line), with corresponding standard deviation (dark grey) and standard error of measurement (light grey) around the test-retest average.

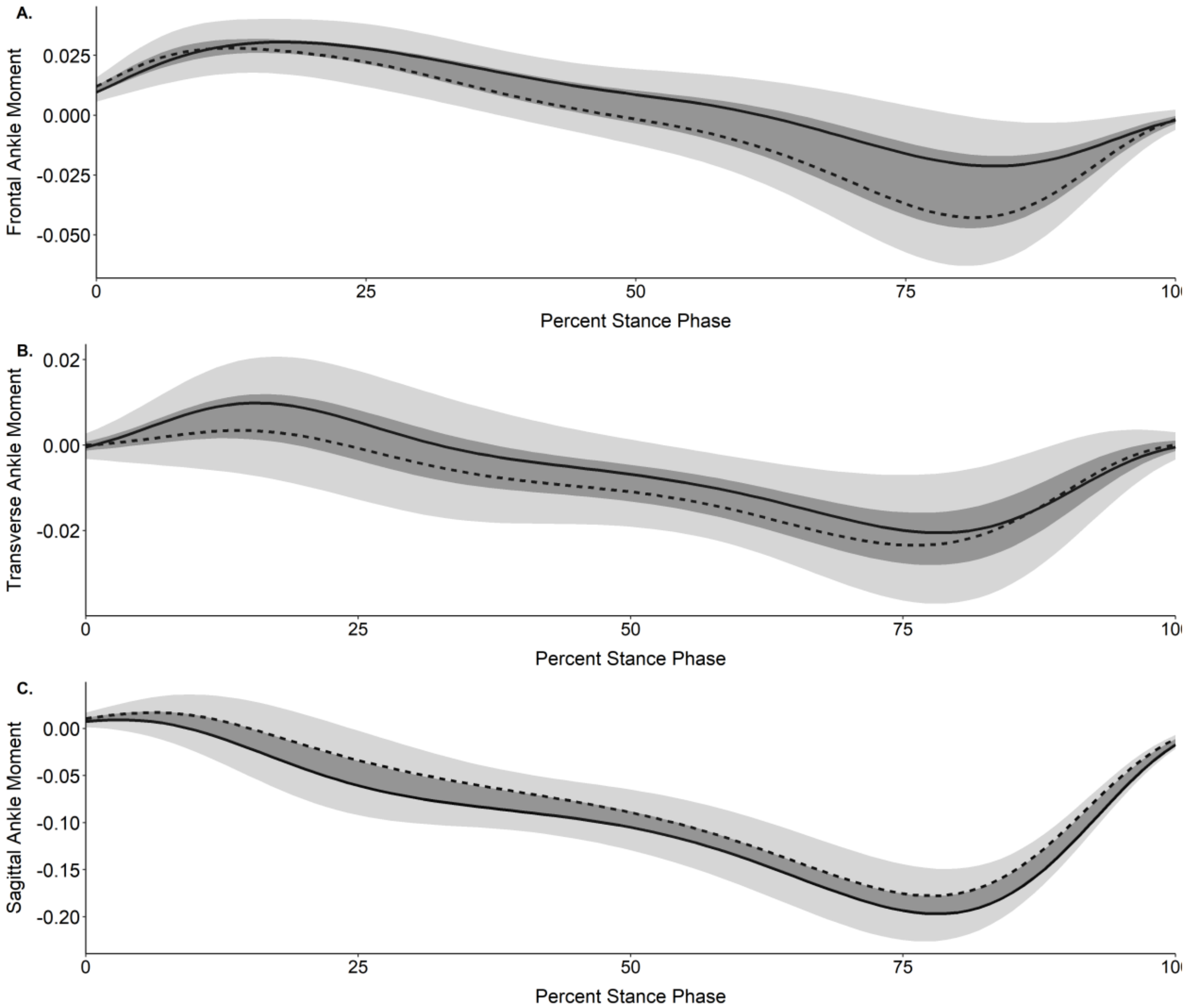

Figure 3-14 Stance phase waveforms of ankle moment in the a) frontal plane, b) transverse plane and c) sagittal plane for the overweight and obese group test (solid line) and re-test (dashed line), with corresponding standard deviation (dark grey) and standard error of measurement (light grey) around the test-retest average.

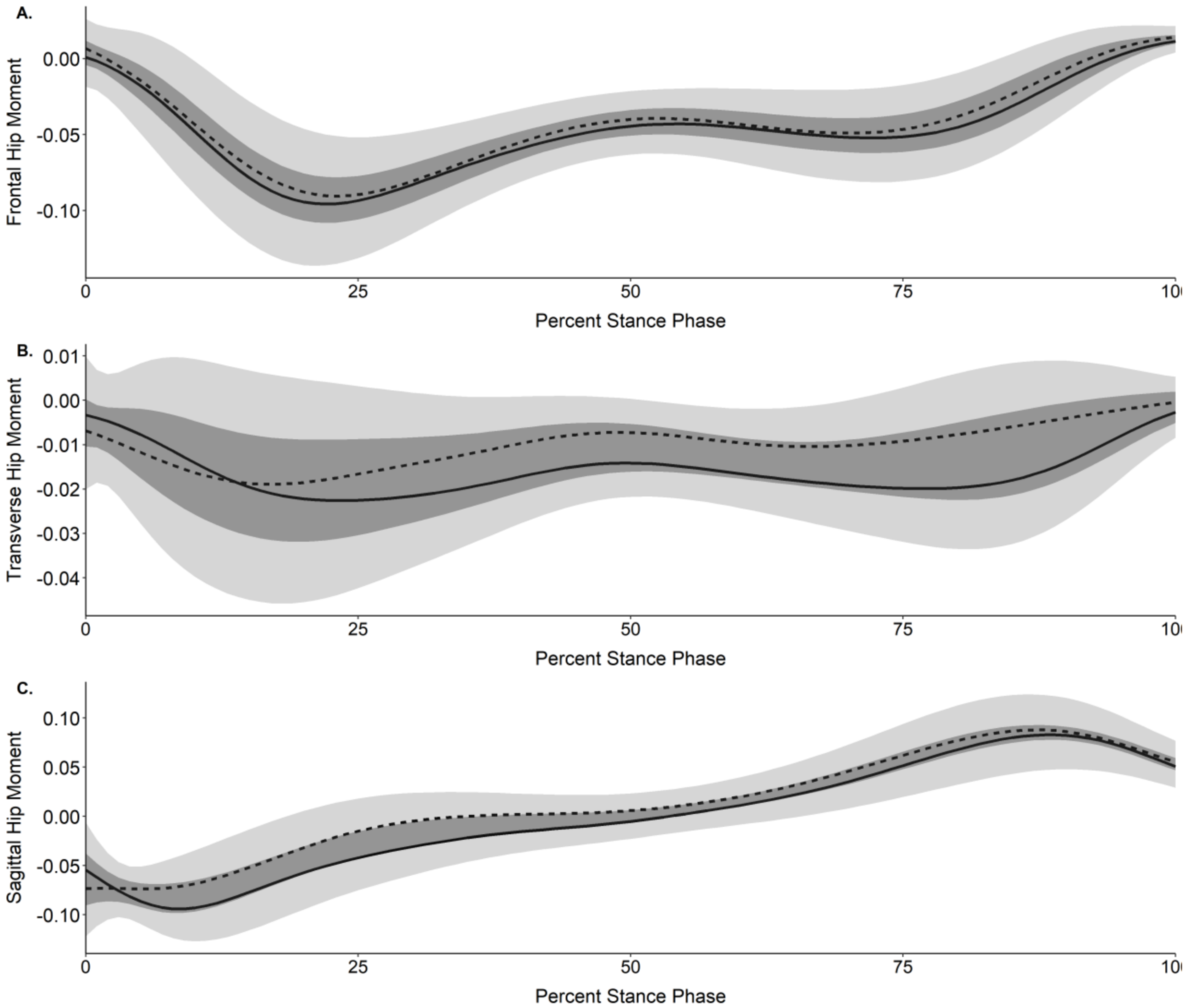

Figure 3-15 Stance phase waveforms of hip moment in the a) frontal plane, b) transverse plane and c) sagittal plane for the overweight and obese group test (solid line) and re-test (dashed line), with corresponding standard deviation (dark grey) and standard error of measurement (light grey) around the test-retest average.

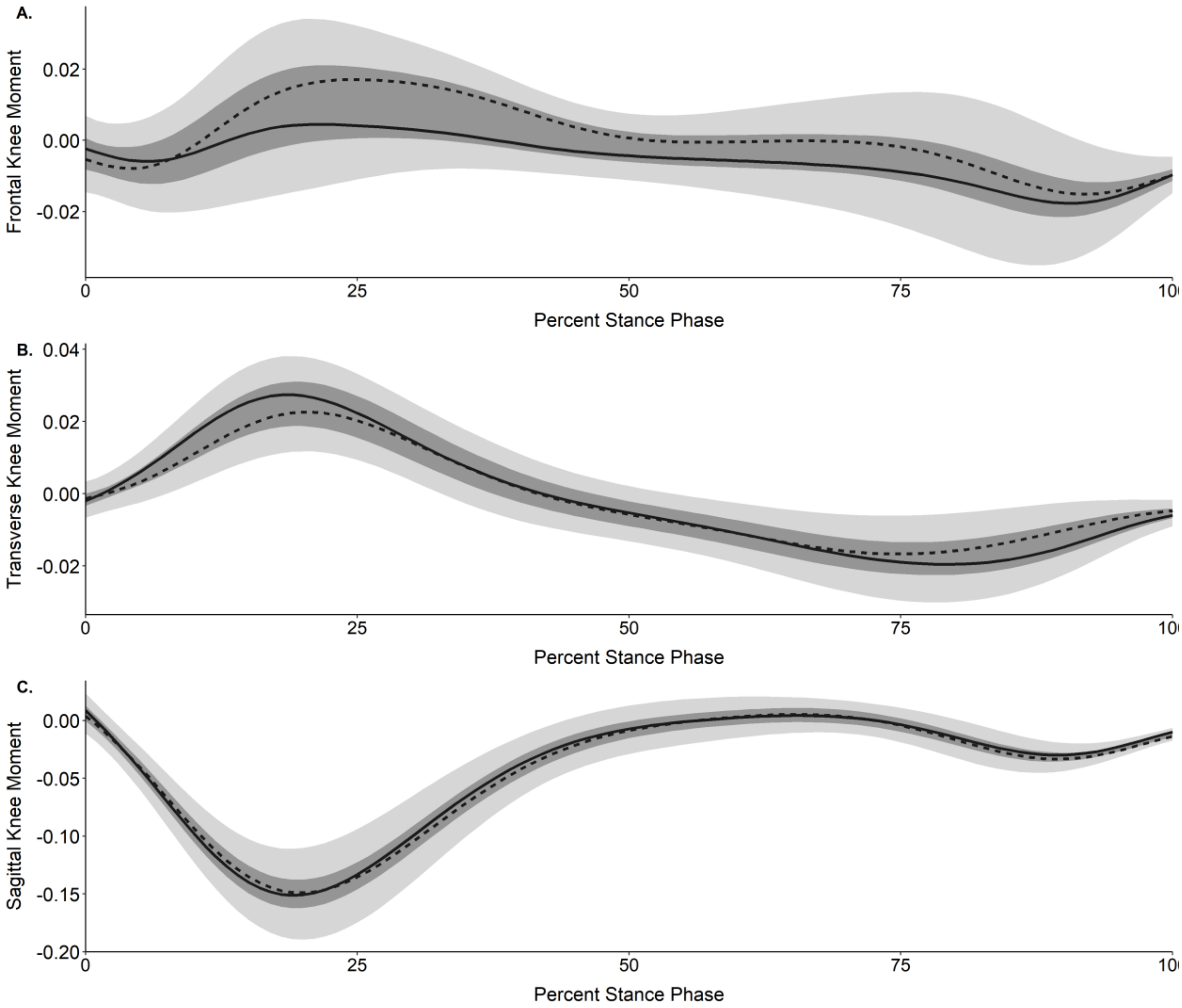

Figure 3-16 Stance phase waveforms of knee moment in the a) frontal plane, b) transverse plane and c) sagittal plane for the overweight and obese group test (solid line) and re-test (dashed line), with corresponding standard deviation (dark grey) and standard error of measurement (light grey) around the test-retest average.

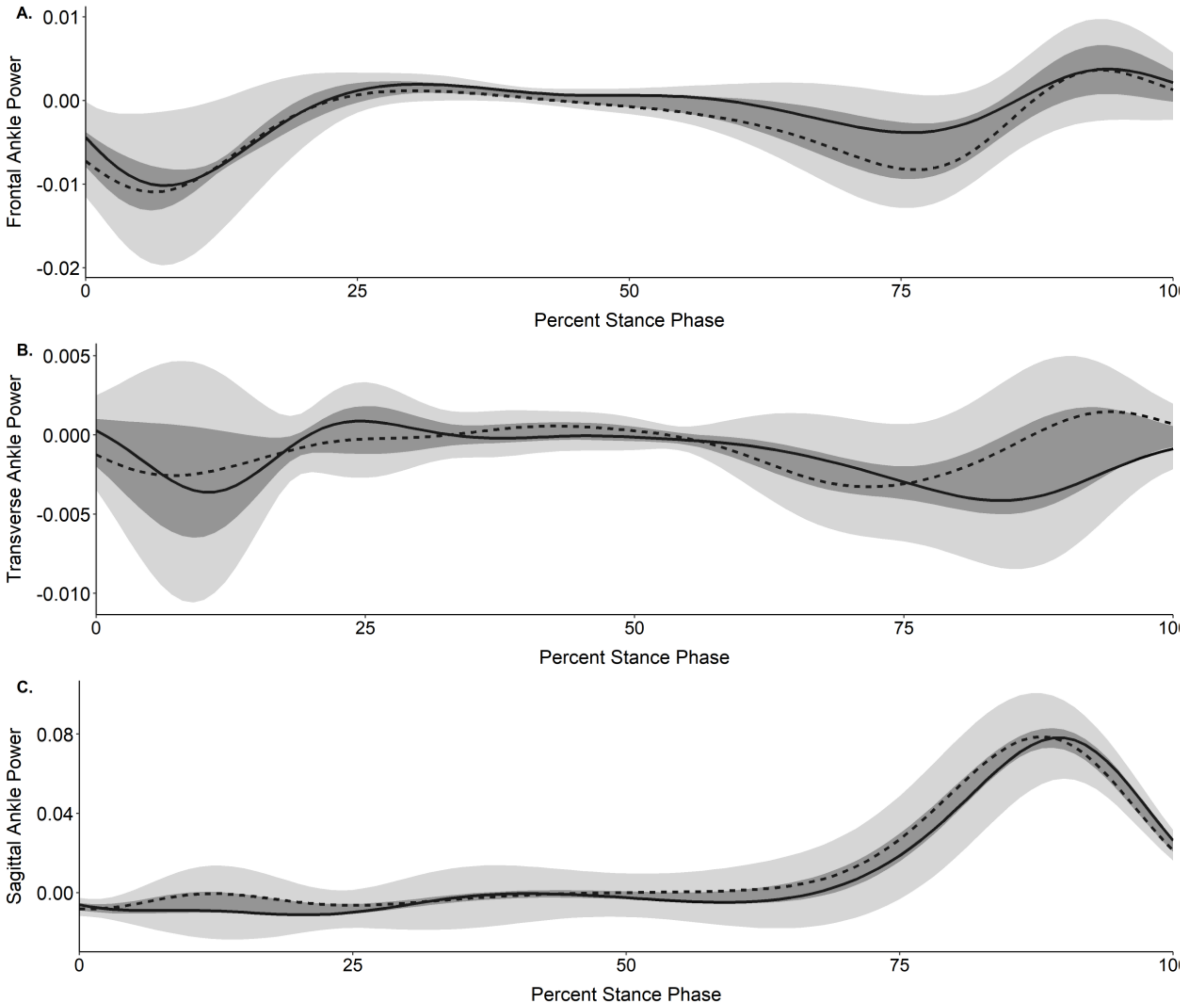

Figure 3-17 Stance phase waveforms of ankle power in the a) frontal plane, b) transverse plane and c) sagittal plane for the overweight and obese group test (solid line) and re-test (dashed line), with corresponding standard deviation (dark grey) and standard error of measurement (light grey) around the test-retest average.

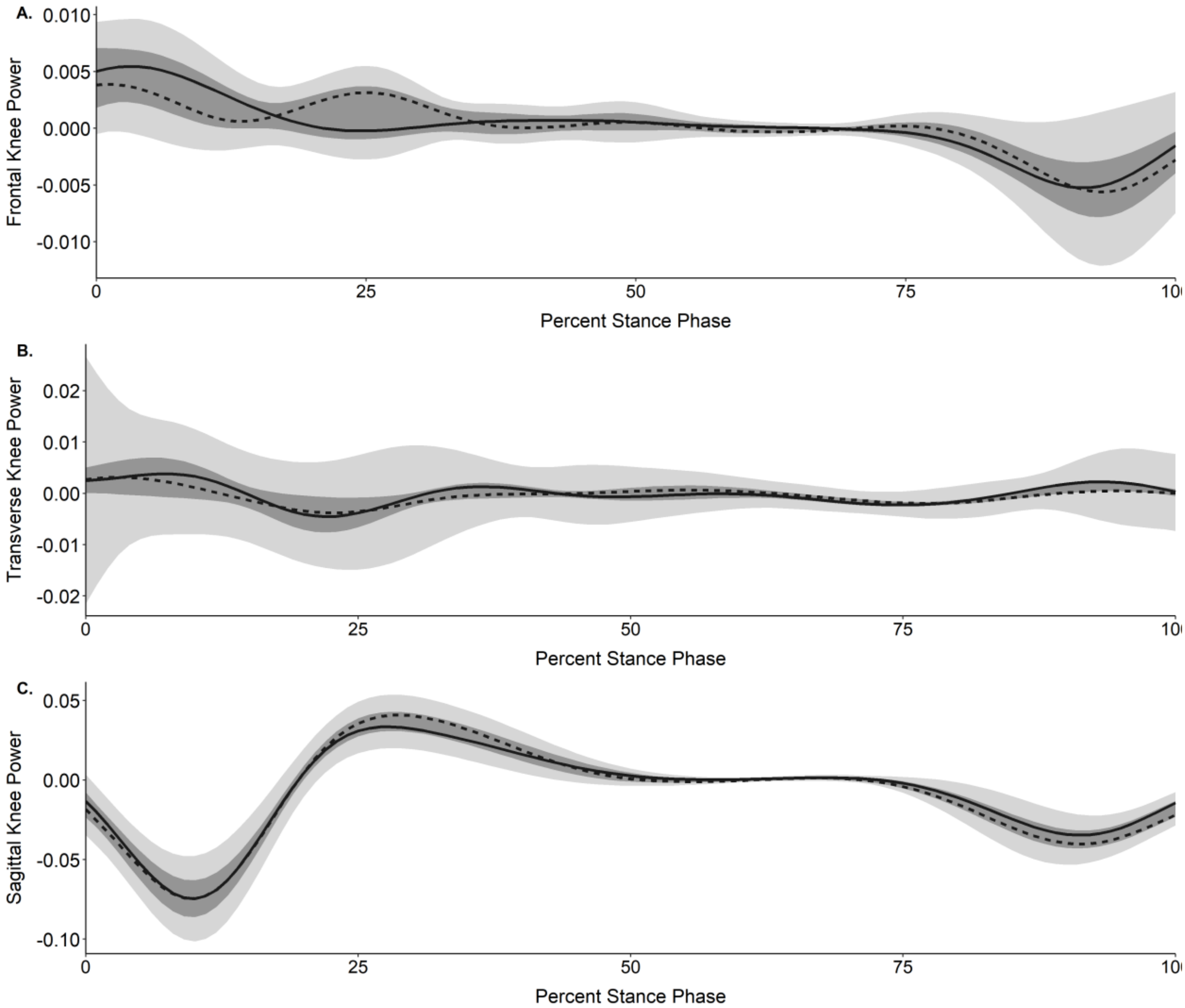

Figure 3-18 Stance phase waveforms of knee power in the a) frontal plane, b) transverse plane and c) sagittal plane for the overweight and obese group test (solid line) and re-test (dashed line), with corresponding standard deviation (dark grey) and standard error of measurement (light grey) around the test-retest average.

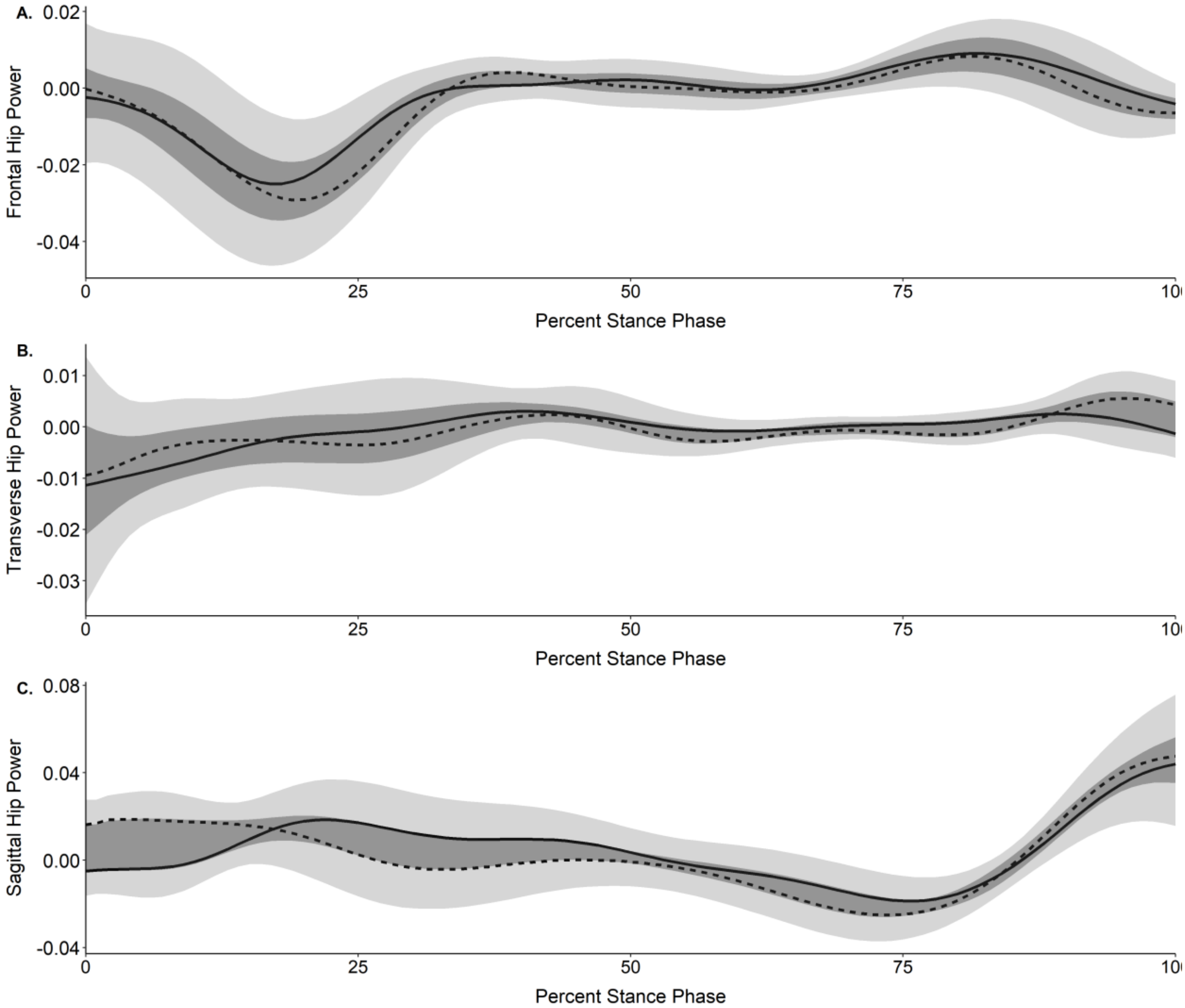

Figure 3-19 Stance phase waveforms of hip power in the a) frontal plane, b) transverse plane and c) sagittal plane for the overweight and obese group test (solid line) and re-test (dashed line), with corresponding standard deviation (dark grey) and standard error of measurement (light grey) around the test-retest average.

3.5 Discussion

Using a test-retest design, the current study investigated the reliability of measures in OWB and TW children. There was a trend for the OWB group to demonstrate higher reliability than the TW group for clinical measures of physical function, isokinetic strength, and temporal spatial parameters of gait, with some exceptions in individual variables. Typically, the OWB demonstrated less variability than the TW group for lower limb joint angles during stance for the frontal and sagittal plane and greater values in the transverse plane. SEM values remained stable over the stance phase waveforms for foot and lower limb joint angles. Frontal and transverse plane joint moments were similar amongst OWB and TW groups, and the OWB group typically had lower SEM values in sagittal plane moments. Joint power was similar between the OWB and TW groups. Examination of joint moment and power waveforms revealed greater variation during stance transitions (around 25% and 75% of stance) for joint moments, and at the beginning and end of stance during deceleration and acceleration periods for joint power.

3.5.1 Clinical measures of physical function

In the test-retest of 6MTW, the OWB group reduced the distance walked at the second time point, while the TW group increased the total distance walked between the test and re-test. This suggests some differences between groups for either motivation or learning effects in repeated testing. The ICC value for the OWB group (ICC 0.80) was similar to that of previously reported test-retest values of 6MTW in obese children (ICC 0.84) by Morinder (2009). The SEM and corresponding MDC value for Participants with OWB in the current group is marginally greater than that reported by Morinder (2009). Morinder (2009) reported a measurement error of 24 m compared to 25.58 m in the current study and an MDC of 67.6 m compared to 70.91 m in the current study, but the MDC% falls within what would be considered 'acceptable'.

STS results showed a greater error in the TW group than in the OWB group, as evidenced by greater SEM values (1.55 vs 4.14 repetitions). This is likely due to the increase of two repetitions in the TW group between trials 1 and 2. Similarly, Reychler et al. (2019) found 8-18-year-olds who were TW also to have an increase in STS repetitions in one-week apart test-retest. The OWB group showed no mean increase between time points, and test-retest values fell within 95% limits of agreement. MDC% fell within the acceptable range (<30%) for the OWB. ICC values for the OWB were good (ICC 0.94) and comparable to previously reported (ICC 0.90) STS rest-retest reliability in children and adolescents (Reychler et al., 2019). The difference in groups in change between test-retest scores may indicate Participants with OWB were already performing at a maximal capacity and, therefore, were not able to increase performance at the one-week re-test through any changes in intrinsic motivation or time perception, as suggested by Reychler et al. (2019).

The TUG test in the current study had an ICC less than previously reported (ICC 0.33 vs 0.80 - 0.95) by Nicolini-Panisson and Donadio (2014) and Williams et al. (2005), which may be a result of the larger age ranges in the previous studies and therefore more heterogeneous groups. Williams et al. (2005) reported the SEM as 0.4 seconds, only slightly smaller than the reported 0.5 seconds for the OWB group. However, Williams et al. (2005) used an SEM calculation that included the ICC and, therefore, may be subject to the same heterogeneity issues.

SLS tests showed good reliability (ICC 0.75 - 0.83), which is similar to other studies (ICC 0.79 - 0.86) examining test re-test reliability of SLS in eyes open and eyes closed conditions (Chuadthong et al., 2023; De Kegel et al., 2011). However, SEM values were high, and differences in test-retest values fell outside the 95% limits of agreement for one participant. Visual examination of the Bland-Altman plots may indicate a learning effect in SLS that is not indicated with the regression line due to the outlier. Conversely, Emery et al. (2005) reported no learning or fatigue effect due to repeated same-day SLS tests or one-week follow-up. Combined with the high MDC% values, this suggests that changes in SLS times pre- to post-intervention or follow-up should be interpreted with caution.

Comparisons between OWB and TW SEM values suggest lower error measurement in children with OWB for 6MTW, STS repetitions, and TUG. As discussed in Section 1.3.4, each of these tests requires elements of strength, cardiovascular fitness and postural stability. It may be that these components limit performance in Participants with OWB, negating any possible learning effects between time points. However, it was noted that there were some participants who fell outside of the 95% limits of agreement. In each of these cases, participants performed less well in the re-test. Standardised instructions were given by the same tester at each time point, and therefore, it is likely that the change in scores for these tests may be due to individuals' motivation to perform the test.

3.5.2 Isokinetic strength

There is no available reliability data for ankle plantarflexion or dorsiflexion isokinetic strength in TW children or children with OWB. However, ICC values in the current study (ICC 0.79-0.96) correspond well with studies in young adults (25.4 ± 2.7 years and 23.1 ± 3.1 years respectively) reporting ICC values between 0.73 and 0.97 for a velocity of 30°/s as in the current study (Gobbo et al., 2019; Gonosova et al., 2018). ICC values for hip extension and flexion in the current study (ICC 0.68-0.95) are greater than that previously reported (ICC 0.49-0.68) for children (6-10 years old; Burnett et al., 1990). Similarly, the current study reported greater reliability in hip abduction and adduction, as evidenced by greater ICC values (0.89-0.94) across both groups compared to Burnett et al., (1990). The differences between Burnett et al. (1990) and the current study may stem from a variation in applied methods. Burnett et al. (1990) employed two testers working interchangeably with participants, whereas the current study used a single tester for all participants at both time points. This consistent approach in the current study likely eliminated potential discrepancies in setup and joint alignment. Additionally, Burnett et al. (1990) noted that verbal commands were not consistent for all participants across both time points, unlike in the current study. Variations in commands and encouragement cues can vary peak torque values within participants (Rendos et al., 2019).

Compared to OWB, TW participants exhibited lower measurement error on hip abduction and adduction in absolute and allometrically scaled strength (SEM; OWB: 0.23-5.83 vs TW: 0.13-5.63 Nm). The side-lying position and hip abduction motion are challenging movements, and any rotation of the body during maximal effort means the movement can be compensated for by hip flexors or extensors. Whilst children were positioned consistently and correctly to the dynamometer axis and supported by the tester so as to limit any rotation and compensatory muscle action, the greater soft tissue of the OWB group, particularly around the hip and legs, may have allowed for more movement than that of leaner TW participants.

Isokinetic knee extension and flexion ICC values for the TW group (0.80 and 0.67, respectively) were similar to that for previously reported reliability of isokinetic knee extension (0.81 and 0.83) and knee flexion (0.62 and 0.76) in prepubertal TW children (Deighan et al., 2003; Fagher et al., 2016). Values of SEM were also comparable for knee extension (SEM 5.37 Nm vs previously reported 5.50 Nm) and greater for knee flexion (SEM 6.59 Nm vs previously reported 3.5 Nm (Fagher et al., 2016). Contrastingly, the OWB group demonstrated greater ICC values for knee extension and flexion (ICC; OWB: 0.81 vs TW: 0.62) than the TW group. Correspondingly, Collado-Mateo et al. (2020) reported higher ICC values in children with OWB for knee extension and flexion (ICC 0.984 and 0.956, respectively) compared to previously cited studies in TW children. The differences in reliability and error between TW and OWB groups, as seen in the current study and comparisons of previous literature, demonstrate the need to examine reliability and variability within the target population to be tested. Whilst Fagher et al. (2016) found a learning effect and increase in peak torque of knee flexors and extensors after a 1-week re-test at a higher velocity (180°/s), they found no effect at the slower 60°/s velocity that was also used in the current study. Similarly, Collado-Mateo et al. (2020) found no learning effect of same-day re-test at 60°/s knee extension and flexion peak torque for children with OWB. Examination of Bland-Altman plots in the current study also corresponds with this, suggesting the familiarisation protocols at each testing point are sufficient to counter any learning effect from repeated testing. Correlation coefficients suggest children with OWB with lower absolute and allometrically scaled hip flexion decreased strength at re-test (also evidenced by mean reduction test to retest) which may be indicative demotivation.

Absolute and allometrically scaled isokinetic strength measurements of the ankle plantar flexors, dorsiflexion, hip extensors and flexors, and knee extensors and flexors all demonstrated good or excellent reliability and MDC% values within the 'acceptable' range. Measurement of hip strength in the frontal plane showed greater error, and changes in these values pre- to post-intervention and follow-up should be interpreted cautiously.

3.5.3 Temporal-spatial gait parameters

The OWB group tended to have a higher ICC for stride distance (OWB: 0.82 vs TW: 0.78), walking velocity (OWB: 0.75 vs TW: 0.47) and stance phase (OWB: 0.77 vs TW: 0.41) compared to the TW group, but greater error (OWB: 0.05 vs TW: 0.01 m for stride distance, OWB: 0.10 vs TW: 0.07 m/s for walking velocity, and OWB: 0.03 vs TW: 0.02 s for stance phase time). It is likely that the greater ICCs in the OWB are affected by the greater participant variation within the group, whilst the greater SEM suggest greater error. Despite this, all MDC% fell within the 'acceptable' threshold. Findings in the TW group are similar to previously reported temporal-spatial reliability in healthy children (ICC 0.30 - 0.74; Stolze et al., 1998). Previously reported obese specific temporal-spatial between-assessor reliability (ICC 0.48-0.94) and SEM values for stride distance (0.04 m), and stance phase timings (0.01-0.02 s) demonstrated similar findings (Horsak et al., 2017). However, Horsak et al. (2017) reported a walking velocity error lower than the current study (SEM 0.04, MDC 0.10 m/s). This difference is likely to Horsak et al. (2017) controlling re-test walking velocity to within 5% of the first test average. The difference between TW and OWB groups in the current study and when comparing across studies highlight the need for OWB-specific SEM and MDC values to compare to post-intervention and follow-up gait changes in the paediatric OWB population.

3.5.4 Centre of mass during single stance phase of gait

There are currently no available data on the mediolateral CoM displacement during stance relative to foot width in children to compare to data in the current study. Maximal mediolateral CoM displacement was more variable and demonstrated a greater MDC% than total mediolateral CoM displacement (50.46% vs 28.32%) in the OWB group, and exceeded the previously defined 30% threshold and, therefore, should be interpreted with caution in intervention studies.

3.5.5 3D Gait foot kinematics

SEM findings in the TW group of the current study (SEM 1.72 – 3.88°) are comparable to previous findings in children using the same IOR foot model (SEM 2.10-4.80°; Mahaffey et al., 2013). However, findings in the OWB groups showed greater measurement error (SEM 1.88-6.52°) compared to TW groups in the current study and from Mahaffey et al. (2013). The greater fat mass on the feet of children with OWB (Riddiford-Harland et al., 2011) may have impacted marker placement consistency from test to re-test despite being completed by the same tester. Inconsistent marker placement will increase joint angle errors (Leardini, Benedetti, et al., 2007).

3.5.6 3D Lower limb gait kinematics.

SEM values for the hip and transverse and sagittal knee angle exceeded 2-5°, which may be considered 'reasonable' by McGinley et al. (2009) in their systematic review of 3D kinematic gait reliability across different participants and lower limb models. However, the current study is in agreement with McGinley et al., (2009) in that hip and knee rotations had the highest errors. In concordance with a study utilising the same lower limb model, frontal plane knee rotations have the lowest error (Leardini, Sawacha, et al., 2007). However, it should be noted that Leardini et al. (2017) reported the average SD of joint rotations as a measure of variability, limiting the direct comparison of error values. Horsak et al. (2017) reported SEM values for obese children and adolescents during gait (with the Cleveland lower limb marker set) of 1.12-3.56°, which is lower than the current study. The difference for this may be the control of walking velocity at the re-test to within 5%, which was not performed in the current study. As a key indicator of function (Middleton et al., 2015), it is important to measure self-determined gait velocity pre- to post-intervention and, therefore, not restrain to post-intervention velocities; it may be important to consider changes in velocity when examining changes in lower limb gait kinematics pre- to post-intervention. Moreover, it is worth noting the use of whole stance phase waveform SEM in the current study compared to discrete values based upon peak angles and angles at initial contact by Horsak et al. (2017). Examination of SEM gait waveforms reveals an increase in error in the 2nd half of stance and terminal stance in the ankle and knee, which may be missed when using only discrete values.

3.5.7 3D lower limb gait kinetics

Typically, measurement error was lower in the OWB group for joint moment and lower or the same as the TW group for joint power. Direct comparisons to previous literature SEM values are difficult due to differences in normalisation techniques of joint moment and power. However, Leardini, Sawacha, et al. (2007) reported sagittal plane joint moments and frontal hip moments to have greater variation (average of SD) compared to frontal and transverse knee and ankle moments, which corresponds well with the current findings. There was a trend for SEM to be greater during stance transitions, such as when the opposite foot is lifting, and single stance begins and then when the opposite foot makes initial contact and stance limb prepares to lift. Similar patterns of variability (i.e. greater variability in stance phase transitions) have been found in comparisons of young adults and older adults (Kowalski et al., 2022). During this period, joint moments work to prevent the collapse of the limb, and joint powers work to decelerate and accelerate the CoM. The increased error around these events may suggest multiple strategies for children with OWB to complete these transitions. Reliability and measurement error in gait kinetics and kinematics are comparable to previous literature, but differences may arise from the range of 3D models and statistical methods used to determine reliability and error. Therefore, some SEM values in the current study exceed what may be considered 'reasonable'. However, the results do provide valuable information for determining change in 3D gait kinetics and kinematics stance phase waveforms in children with OWB beyond the error of measurement.

3.5.8 Limitations

The current study is limited in providing information beyond test-retest reliability (e.g. consistency of procedures [operator effects], and learning effect [participant effects]). Whilst children previously demonstrated a learning effect in isokinetic dynamometry, this is thought to be mitigated by familiarisation. Familiarisation (completed during each testing session and for each movement) in the current study appeared sufficient for hip extension, knee extension/flexion, hip abduction/adduction and ankle plantarflexion/dorsiflexion. However, increased hip flexion values at re-test (Figure 3-3 and 3-5) in the strongest participants may suggest a learning effect but more work in OWB paediatric populations is needed to explore this. Additionally, the broad range of age, maturation and abilities likely contributed to the heterogeneity in some tests, which may have impacted ICC values. However, the calculation of SEM and MDC did not include the ICC. Therefore, measurement error values were independent of the effect of heterogeneity. Moreover, test-retest values may have been impacted by participants' emotional state on the day, possibly exhibiting a demotivational effect on 1-week re-test, which may compound reliability statistical values.

3.5.9 Implications

The current study provides reliability statistics for isokinetic dynamometry, 3D foot, and mediolateral CoM during gait in OWB 7-11-year-olds and provides MDC values that may be used to determine meaningful change in physical function from intervention in children with OWB. This study demonstrates the necessity of population-specific reliability and MDC data, as evidenced by the differences between TW children and children with OWB. Applying MDC values derived from TW children to children with OWB may lead to meaningful changes from interventions, particularly in clinical physical function tests and isokinetic dynamometry, being overlooked. This is because changes that fall below the MDC thresholds established for TW populations might still be meaningful when assessed against the typically lower MDC thresholds (Table 3-3, 3-4, and 3-5) calculated for children with OWB. Reliability and MDC statistics presented in the current study may be used in both clinical and research settings. Moreover, examination of variability over the entire gait waveform demonstrates increased variability around step-to-step transitions in children with OWB, which may warrant further investigation in future work.

3.6 Conclusion

Some clinical physical function test (TUG and SLS) and temporal-spatial parameters of gait were affected by the heterogeneity of data within each group as ICC's were higher (compared to TW groups or previous literature) but SEM values were also higher. Greater consistency of results (as indicated by greater ICC values) and lower error (as indicated by lower SEM) in the OWB group compared to TW for other physical function tests (6MTW and STS) and strength measures may suggest that greater body mass may be a limiting factor to performance beyond that of any performance benefit from learning effects. However, this does not negate a reduction in performance (as evidenced by outliers in data) from factors such as motivation. Burnett et al. (1990) described outliers in their own study were due to children's effort and motivation being affected by external and uncontrolled factors.

It was also noted that greater subcutaneous FM may influence the precision of marker position between testing days and increase vibration movement during walking trials (Leardini et al., 2007). The differences observed between the OWB and TW groups in the current study underscore the importance of OWB child-specific reliability, SEM, and MDC values for intervention research. This ensures that any detected differences exceed the measurement error specific to children with OWB. Whilst some MDC% values within the current study may be defined as outside the <30% 'acceptable' (Smidt et al., 2002), current inclusion of measures have been chosen for their applicability to clinical settings or rigorous laboratory methods in which many confounding factors are controlled for. Additionally, some 3D gait kinematics exceed the previously reported and commonly cited error of >5° (McGinley et al., 2009) However, the difference in waveform SEM estimation, test-retest methods, and particular considerations for OWB and paediatric participants may explain this increase in error. Nevertheless, what is reported in the current study is population- and method-specific measurement error, which may be directly applied to the later intervention studies (Chapter 6) to determine the change from adaption as a result of the intervention beyond that of any measurement error.

4 Pilot study of a school-based exercise programme in children with overweight and obesity.

4.1 Abstract

This pilot study aimed to assess the implementation of a school-based exercise intervention for children with overweight and obesity to improve muscular strength and postural stability. It evaluated participants' attendance, enjoyment, and views of the intervention while estimating the intervention's impact on physical function and physical well-being. The study examined a 9-week exercise intervention held twice weekly at schools, incorporating dynamic warm-ups, lower limb strength and stability exercises. Pre-, post-intervention, and follow-up testing of physical well-being and physical function measures were conducted at St Mary's University. Seven overweight and obese children in the experimental group and seven overweight and obese children in the control group completed pre-, post-intervention, and follow-up testing. Twelve overweight and obese children who completed the exercise intervention additionally took part in a focus group to examine their views of intervention sessions. Focus groups were audio recorded, and thematic analysis followed a familiarisation, identification, indexing, charting and mapping process. Intervention attendance was impacted by participants choosing not to attend. Focus groups identified key areas for intervention development, including session timing, novelty, and play. As a result of the intervention, the experimental group showed improved single leg stance performance, increased hip and knee strength, reduced mediolateral centre of mass velocity, and narrower step width, while both groups exhibited changes in lower limb kinematics. Future interventions should prioritise attendance, engagement, and developmental appropriateness by using a co-production approach to refine school-based exercise interventions in overweight and obese children.

4.2 Introduction

Obesity is an increasing global problem and one of the biggest current challenges in public health (Di Cesare et al., 2019). Childhood overweight and obesity (OWB) has lasting health consequences, including musculoskeletal (MSK) pain, reduced physical activity (PA), poorer quality of life, and impaired physical function, necessitating interventions to address these deficits in children with OWB (Lobstein & Jackson-Leach, 2016; Tsiros et al., 2011). Interventions in the school setting can reach a broad spectrum of children, independent of socioeconomic status, thereby removing time and economic barriers for parents and guardians (Graf et al., 2008). Before conducting an exercise intervention study, it is recommended (Thabane et al., 2010) to determine the feasibility of conducting the intervention and data collection protocols and to pilot the intervention study to inform a main study.

Resistance training has consistently been shown to improve strength in children with OWB (McGuigan et al., 2009; Alberga et al., 2013). Improvements in measures such as one-repetition maximum (1RM), hand-held dynamometry (HHD), and isokinetic dynamometry tests indicate significant gains in muscular strength, likely resulting from neural adaptations due to the high neural plasticity observed in prepubertal children (Sánchez Pastor et al., 2023). Furthermore, resistance training may provide psychological benefits, as children with OWB often outperform typical weight (TW) children in absolute strength measures, boosting confidence and motivation (Schranz et al., 2013). While longer (16 weeks +) interventions may enhance power production

(Sgro et al., 2009), an 8-week resistance training program is sufficient to yield measurable strength improvements, making it a practical and achievable intervention duration. Additionally, static and dynamic exercises that increase demands on postural stability (e.g., unilateral stance and hopping) also show measurable improvements in static and dynamic stability within short timeframes of 4–12 weeks (Guzmán-Muñoz et al., 2019). These adaptations can enhance physical function and reduce functional limitations associated with obesity.

Adequate attendance and adherence (i.e. engaging in exercises as designed) to interventions are essential for determining the effectiveness of exercise programs. Studies implementing exercise programs to address MSK disorders have reported beneficial outcomes when adherence rates exceed 80% (Mazières et al., 2008; Steinhilber et al., 2012). Exercise interventions targeting children with OWB have shown improvements in muscle strength with average attendance and adherence rates above 83% (Alberga et al., 2013; McGuigan et al., 2009; Treuth et al., 1998). However, some studies report challenges such as low attendance (<70%; Horsak et al., 2019) and high dropout rates (>20%; McGuigan et al., 2009), which are common issues in exercise interventions targeting OWB youth (Alberga et al., 2019).

Poor attendance or adherence in children with OWB has been attributed to environmental barriers, such as time constraints and limited access to facilities—issues that are mitigated by conducting interventions in school settings. Additionally, factors like boredom, low self-confidence, and lack of enjoyment further hinder participation (Alberga et al., 2019; Holt et al., 2020). As discussed in Sections 1.4.1 and 1.4.2, previously conducted exercise interventions in children with OWB that reported low attendance and high drop-out rates likely failed to meet the needs of participants. OWB adolescents who participated in exercise interventions and healthy lifestyle programmes identified barriers such as mood, body image concerns and poor motivation (Alberga et al., 2019; Kebbe et al., 2017). Additionally, common barriers to intervention in children and adolescents with MSK conditions (e.g. osteoarthritis, cystic fibrosis etc.) broadly include feelings around their own capability, opportunity (i.e. time constraints and physical environment) and motivation (Holt et al., 2020). Similar insights into the experiences of children with OWB who participated in exercise interventions are lacking. This gap in understanding limits the ability to address known barriers to attendance and adherence effectively.

Self-determination theory (SDT) provides a framework for understanding motivation quality (Guay et al., 2000; Ryan & Deci, 2017). It highlights the importance of fulfilling Basic psychological needs (BPN)—autonomy, competence, and relatedness—to foster intrinsic motivation (Guay et al., 2000; Ryan & Deci, 2017; Stellino & Sinclair, 2013). When children feel competent, autonomous, and connected, their motivation and enjoyment of PA increase in both unstructured play (e.g., school recess) and structured activities like physical education (PE) lessons and exercise interventions (Aart et al., 2015; Burns et al., 2017; Gao et al., 2013; Stellino & Sinclair, 2013). SDT provides a framework from which to investigate participants enjoyment and motivation to participate in an exercise intervention. By testing a school-based exercise intervention in this controlled environment, the study aimed to assess participation rates, identify potential challenges, and refine the intervention to enhance engagement and enjoyment.

Therefore, the aims of this pilot study were to determine the practicalities of implementing an exercise intervention specifically for children with OWB within a school designed to increase muscular strength and postural stability. Additionally, this study will determine participants' attendance, enjoyment and views of the intervention within the SDT framework. Finally, this study will aim to estimate the effectiveness of the exercise intervention on relative strength, gait kinetics and kinematics, physical function, and physical well-being.

4.3 Methods

4.3.1 Participants

OWB children aged 7 to 11 years (male and female) were recruited from a school in the London borough of Bexley. The school determined their preferred year groups and classes to take part in the study (opting to avoid disruption to exam periods and planned offsite activity such as swimming) as well as the timing and location within the school of sessions that best fit the school's availability. Participants were excluded from analysis if they had any medical condition or injury affecting neuromuscular or orthopaedic integrity resulting in altered foot posture or gait disturbance. Additionally, TW participants, assessed by age and gender-specific body mass index (BMI) Z-score based on UK90 reference curves and Department of Health thresholds (Cole et al., 1995), were excluded from analysis but were included in activity sessions to reduce the risk of any stigmatisation. Seven participants were recruited in the control group and fourteen in the experimental group (group allocation was based on school timetabling and which children would be able to attend additional sessions in the school day during the study period). Parental or guardian consent was obtained for each participant (Appendix F). Ethical approval was provided by St Mary's University Ethics Committee (Appendix E).

4.3.2 Study design

Testing took place from the beginning of the spring term (January 2019). Participants attended baseline testing over a two week period, after which the intervention programme began. The experimental group completed nine weeks of exercise intervention (1-week rest over the half term). Both experimental and control groups returned for post-intervention testing in the two weeks after the intervention period. Participants then returned for follow-up testing three months after the end of the intervention. Data collection of physical well-being and physical function measures including 3D gait analysis were conducted as per protocols outlines in Chapter 2. All pre-intervention, post-intervention, and follow-up testing occurred at St Mary's University Twickenham, and interventions took place at the school.

4.3.3 Intervention design

The intervention sessions were 1 hour long, held twice a week in the afternoons, and included a dynamic warm-up, core stability exercises (bodyweight plank and glute bridge), and six key exercises outlined in Table 4-1. To ensure intervention fidelity, the same researcher conducted all intervention sessions. Exercise intensity progressed through increased external load in accordance with the training overload principle, while volume steadily increased during weeks one to four, following the training progression principle. After a 1-week half-term break, designed as a recovery microcycle, week six resumed at the same level as week four. Weeks seven and eight saw further increases in volume, followed by a taper in week nine to prepare for post-intervention testing, aligning with standard tapering strategies (Pritchard et al., 2015). Progression in intensity and volume was guided by the validated children's OMNI-resistance exercise scale of perceived exertion, with a reported value below 7 prompting adjustments to increase intensity or volume (Robertson et al., 2005). One session per week was conducted indoors during PE lessons, and the second session took place outdoors during lunchtime, based on the availability of the recruited schools. The control group continued with normal school activities.

Table 4-1 . Pilot intervention exercises, progression and relative strength or stability component.

Exercise	Progression	Strength Component	Dominant Regime of Muscular Work	Stability Component
Sit to Stand with added weight	Increased external load	Hip extensor & knee extensor strength.	Eccentric Concentric	Moving and control the centre of mass in vertical and anterior-posterior direction. Transition from large to smaller base of support.
Monster walks	Increased load via resistance bands	Hip abductor strength	Concentric	Moving and control the centre of mass in medial-lateral direction.
Hip thrust	Increased external load	Hip extensors	Concentric	
Nordic hamstring exercises	Progressively slowed the movement	Knee flexors	Eccentric	
Hops	More complex patterns and distance of hops	Lower limb strength and stiffness	Stretch-shortening cycle	Dynamic unilateral movement in anterior-posterior and medial-lateral direction.
Step up	Increased resistance on the back (moving) leg.	Hip flexors of back leg. Hip extensors and knee extensors of stance leg.	Concentric	Unilateral balance on stance limb

4.3.4 Measuring attendance and adherence

Attendance for the intervention was recorded using a register at the start of each session, with reasons for non-attendance documented. Attendance was calculated as the percentage of total exercise sessions attended. Adherence to the exercises was self-reported through logbooks, where participants recorded their OMNI-RPE for each exercise in every session. If a participant did not perform an exercise, they left the OMNI-RPE section blank for that exercise. Additionally, if they completed fewer repetitions or sets than prescribed, they were asked to record this information. Adherence was calculated as the percentage of exercises completed per session and averaged over the total intervention period, excluding days when participants were absent.

4.3.5 Basic Psychological needs satisfaction and enjoyment

After completion of the 9-week intervention, participants in the experimental group completed a modified (Moore et al., 2009; Motl et al., 2001) 16-item PA enjoyment scale (PACES) scoring on a 5-point Likert scale (1= "Disagree a lot" to 5 = "Agree a lot"). Moore et al. (2009) found this modified questionnaire to be valid in assessing the enjoyment of PA in children. Positively and negatively (reverse scoring) worded items were scored and averaged.

At the same time point, experimental group participants completed the competency, autonomy, related and teacher relatedness scale (CARR) previously found to be reliable and valid in children (van Aart et al., 2015; Vlachopoulos et al., 2011). The questions are grouped together to create four subscales, competence, autonomy, classmate relatedness and teacher relatedness. Items in each subscale were scored 5-point Likert scale (1=" disagree a lot" to 5 =" Agree a lot") and averaged to create a score for each. The introductory sentence for each questionnaire was modified to be specific to the intervention.

4.3.6 Focus groups.

Focus groups were held in school and moderated by the same researcher who administered the exercise interventions. Groups were split into younger (7-8 years) and older groups (9-10 years). A semi-structured question guide was used, and questions were based on how the intervention sessions made them feel, their level of enjoyment, and what they would have preferred to do. Additionally, the focus group included activities, such as drawing exercises and looking at images of the OMNI RPE scale to maintain engagement. Thematic analysis of focus groups followed a familiarisation, identification, indexing, charting and mapping process (Rabiee, 2004).

4.3.7 Statistical analysis

Cronbach's (1951) alpha coefficients were calculated to determine internal consistency for the PACES questionnaire and each of the basic psychological needs and subscales of the BPNES. An alpha of >0.7 would be considered acceptable internal consistency (Taber, 2018). The relationship of enjoyment and different needs subscales with overall attendance rate and voluntary non-attendance (number of sessions chosen not to attend) was assessed using linear regression. The attendance rate was entered as the dependent variable, and each scale score was entered singularly as the independent variable. The level of significance was set at 0.05.

Formal hypothesis testing is inappropriate for pilot studies given the low participant numbers and, by their nature, will likely produce non-significant results at the traditional $p<0.05$ level (Arain et al., 2010; Lancaster et al., 2004). Descriptive analysis is suggested to be more appropriate for pilot and feasibility studies with less emphasis on traditional hypothesis testing, as required assumptions are unlikely to be met, resulting in erroneous conclusions (Grimes & Schulz, 2002; Lancaster et al., 2004). Given the low power, as stated above, and the need to provide descriptive data to further inform the development of interventions, it has been recommended that pilot trials focus on confidence interval estimation rather than rely on hypothesis testing alone (Lancaster et al., 2004; Lee et al., 2014). Therefore, 75% confidence intervals for the treatment effect were calculated for the mean difference between groups for all variables at pre-intervention, post-intervention and follow-up (Lee et al., 2014). Any 75% confidence interval that did not cross 0 would be interpreted as a possible effect of the intervention (Simonet et al., 2020). Confidence intervals between groups for gait kinetics and kinematics were calculated using statistical parametric mapping (SPM) of two sample difference confidence intervals in Matlab 2022b (Mathworks, 2022; Pataky et al., 2015). SPM allows analysis for comparisons across the entire waveform, meaning no data is lost to data reduction techniques or the selection of discrete time points. Additionally, SPM analysis of the whole waveform allows for any temporal patterns (e.g.

different timing of moment peaks in the gait cycle) to be identified, which would otherwise be lost when using discrete measures (Pataky et al., 2015).

4.4 Results

Of the initial 14 recruited participants, one declined to take part in body composition measurements, effectively withdrawing at baseline testing. Four participants were not able to participate in baseline testing due to the limited time available to collect data. The time limitation of data collection was in part due to the length of the protocol and the availability of the school to visit the laboratory. These participants still participated in the exercise intervention and are included in the attendance analysis and focus groups. Of those who completed baseline testing and began the exercise intervention, one participant withdrew during the intervention period and did not complete the post-intervention questions or focus groups. Lastly, one participant who completed baseline and post-intervention testing was later excluded for disclosing an inner ear condition affecting their balance that was not initially disclosed in pre-intervention screening (this participant is included in the attendance and adherence analysis). Seven remaining participants are included in the baseline, post-intervention, and follow-up analysis. No participant withdrew from the control group.

Table 4-2 Characteristics of participants included in the analysis of attendance analysis and focus groups, and experimental and control group of pre-, post- and follow-up intervention analysis.

	Attendance. adherence and focus group *n*=12	Pre, post, and follow-up analysis intervention group *n*=7	Pre, post, and follow-up analysis control group, *n*=7
Gender	7 boys, 5 girls	2 boys, 5 girls	2 boys, 5 girls
Age (yrs)	8.93 ± 1.00	8.99 ± 1.12	8.90 ± 0.28
Body Mass (kg)	43.18 ± 12.23	44.47 ± 15.06	42.89 ± 5.14
Height (cm)	141.53 ± 12.70	140.93 ± 15.81	138.81 ± 5.88
Weight Status	8 obese, 4 overweight	4 obese, 3 overweight	6 obese, 1 overweight
Z-score	1.88 ± 0.57	1.96 ± 0.67	2.14 ± 0.69

4.4.1 Attendance and adherence

Mean attendance to the intervention programme was 73% and ranged from 37.50% to 100%. Reasons for non-attendance were no PE kit (4.08%), other school responsibility (8.16%), poor weather (8.16%), absence from school due to sickness (20.41%), and voluntary non-attendance (chose not to attend; 59.18%). Participant adherence (as measured by filling in the OMNI-RPE) was an average of 90.93% of all exercises across the intervention period (ranging from 61.98% to 100%). However, anecdotally it was noted that participants may have falsely reported completing exercises or all prescribed sets and repetitions. The mean attendance of the n=7 participants included in the analysis of physical well-being and physical function in Section 4.4.4 to 4.2.10 was 74% and mean adherence was 92%.

4.4.1.1 Basic psychological need satisfaction and enjoyment.

Cronbach's (1951) alpha score for PACES was 0.82 for positive responses and 0.63 for negative responses. Cronbach's (1951) alpha scores for each subscale of CARRS were 0.42 (autonomy), 0.7 (competence), 0.75 (classmate relatedness), and 0.6 (teacher-relatedness). Average scores for PACES and CARR are shown in Table 4-3.

Table 4-3 Mean post-exercise intervention responses to PACES and CARRS questionnaires.

	Mean ± SD
PACES	3.78 ± 0.68
BPNES Autonomy	3.49 ± 0.62
BPNES Competence	3.63 ± 0.58
BPNES Classmate relatedness	3.96 ± 0.68
BPNES Teacher relatedness	3.96 ± 0.65

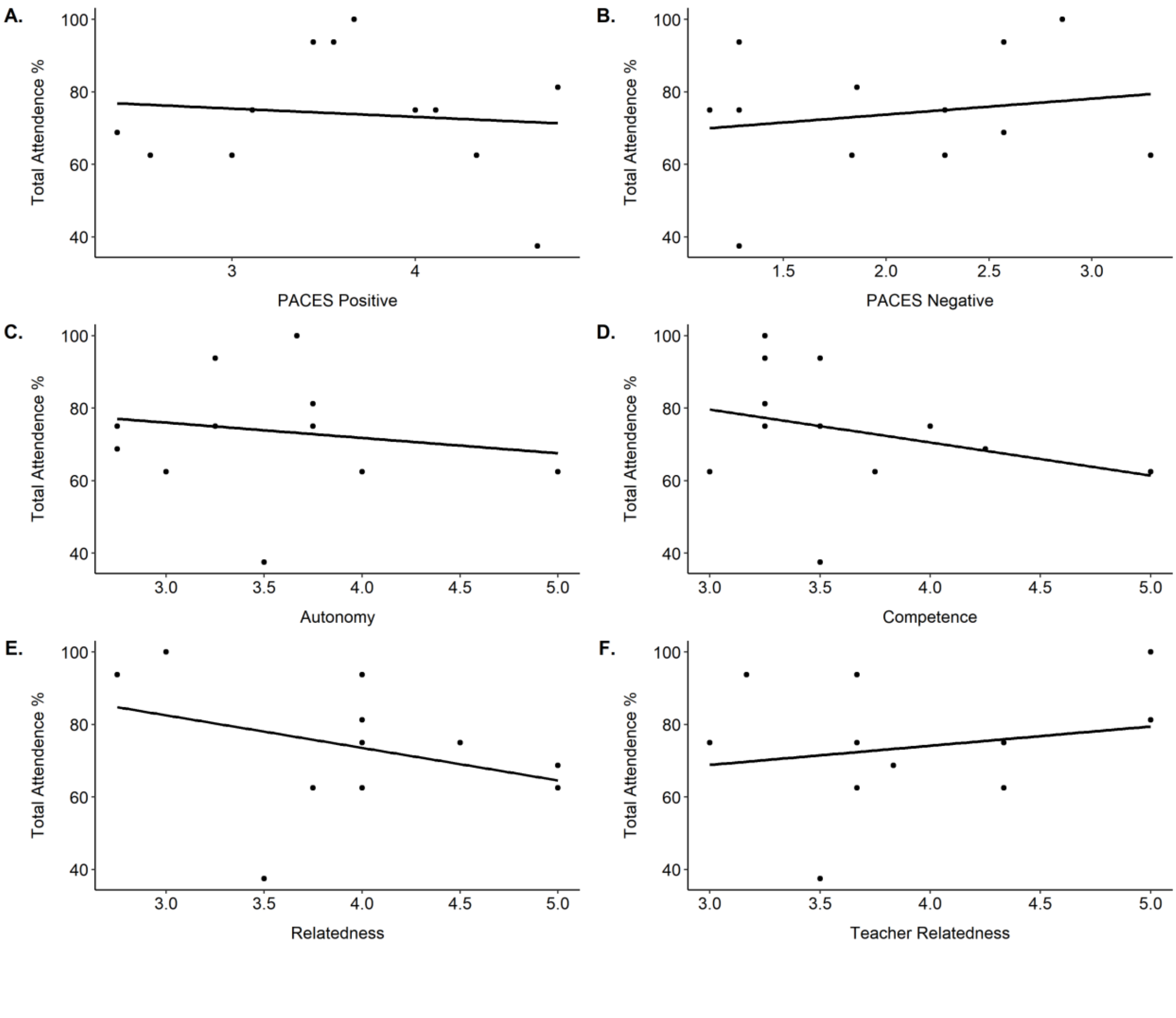

Figure 4-1 Scatter plot illustrating the relationship between physical activity enjoyment scale (PACES) and competency autonomy relatedness and teacher relatedness scale (CARR) questionnaires and percent of total attended sessions. Black line shows the line of best. A) score for positive related PACES questions, B) score for negative related PACES questions, C) score for autonomy related *CARR* responses, D) score for competence related *CARR* responses, E) score for relatedness related *CARR* responses, F) score for teacher relatedness related *CARR* responses.

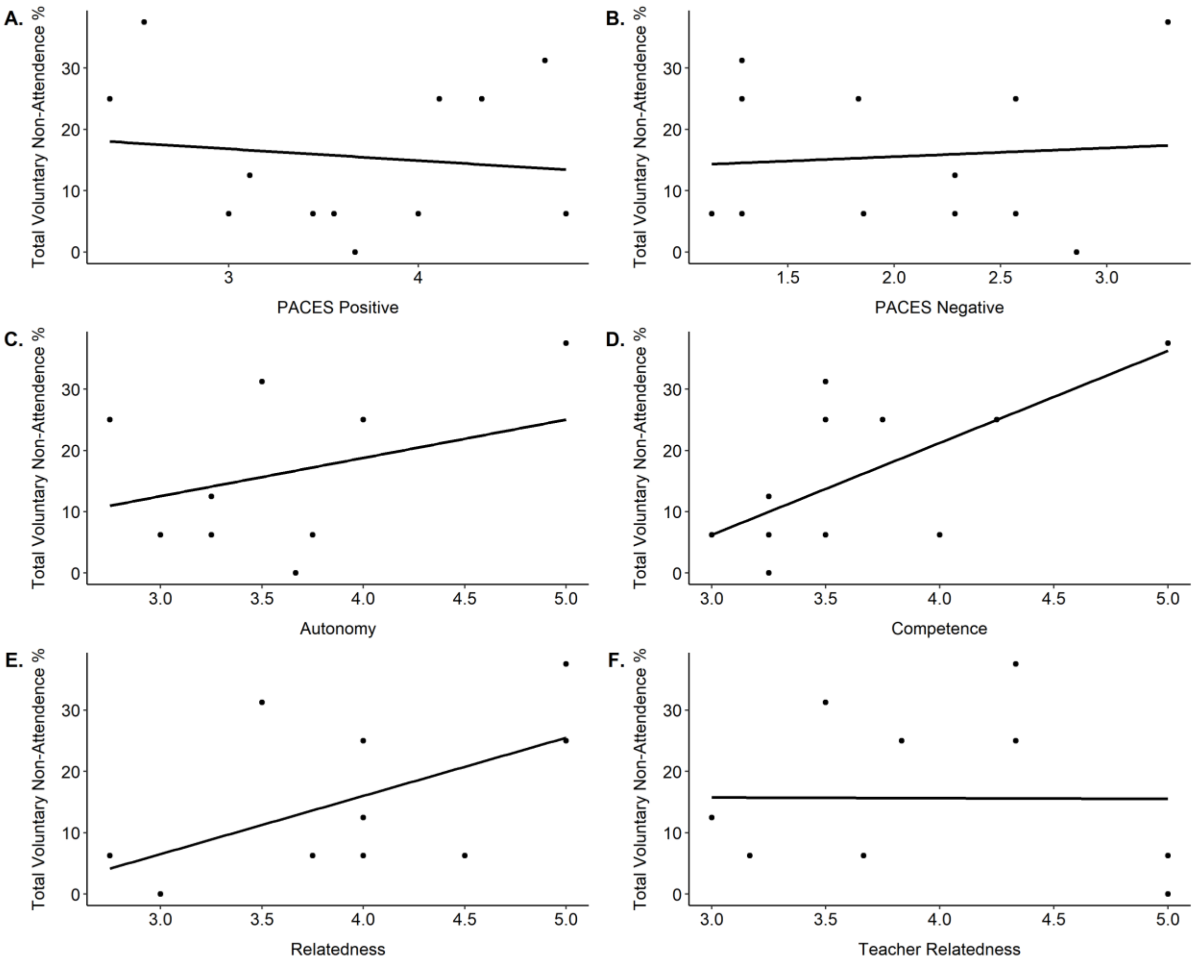

Figure 4-2 Scatter plot illustrating the relationship between physical activity enjoyment scale (PACES) and competency autonomy relatedness and teacher relatedness scale (CARR) questionnaires and percent of total voluntary non-attended sessions. Black line shows the line of of best. A) score for positive related PACES questions, B) score for negative related PACES questions, C) score for autonomy related *CARR* responses, D) score for competence related *CARR* responses, E) score for relatedness related *CARR* responses, F) score for teacher relatedness related *CARR* responses.

Enjoyment was not significantly associated with total attendance (%) or voluntary non-attendance (%). Autonomy, relatedness or classmate relatedness were not associated with total attendance (%) or voluntary non-attendance (%). Feelings of competency was significantly correlated with rates of total non-attendance (r = 0.679, p =0.015). Figure 4-1 and 4-2 visualise the relationship between questionnaire responses and attendance.

4.4.2 Focus group analysis

4.4.2.1 Lunchtime is free time for friends and a choice over activities.

The first theme derived from the focus groups surrounds the timing of sessions during the lunch break. These were the least attended sessions. Participants saw the obligation of attending activity sessions during their lunch break as a withdrawal of time that is typically theirs to spend with friends and free for them to choose activities. When asked for reasons why they chose not to attend lunchtime activity sessions, participants responded, "…because you'd rather be with, and talk to friends" (P1). Moreover, a reason often cited for not attending lunchtime sessions was that lunchtimes were a time in the school day they "..can do what [they] like to do". The majority of male participants preferred to play football, stating, "I never ever ever [wanted to attend lunchtime sessions], because it was a waste of break, [I'd rather play] football" (P2). However, sessions did provide an alternative PA for those who did not enjoy or play football during lunch times, and if friends also attended, then, it became an accepted lunchtime activity.

4.4.2.2 Perception and understanding of the intervention as traditional exercise and differentiation of this to play.

When asked about their understanding of exercises in the intervention, participants typically responded with general terms such as to 'keep fit' or 'train muscles'. It is unclear in what way these terms were understood or if they were parroted as a superficial understanding of the benefits of exercise. Participants did not associate play with exercise; despite being physically active during play, participant 5 stated, "… I'd rather play with my friends than exercise". Intervention sessions were viewed more akin to traditional exercise, and children perceived PA differently during play. Despite the preference for what they deemed as play over exercise, participants did state that the intervention could be improved with the use of more traditional gym equipment such as dumbbells. However, this may relate more to the need for novelty over the desire to partake in these sorts of activities.

4.4.2.3 Amotivation from negative experiences, lack of novelty, and lack of challenge.

The third theme developed from focus groups centred around amotivation of participants to engage with the intervention and suspected route causes of this amotivation. During an exploration of views on the sessions, participant P3 stated, "it wasn't really boring, but it wasn't really interesting to me", whilst others expressed a strong dislike saying they "never in a million years [wanted to attend]" (P8). Amotivation for activities is thought to be related to a thwarting of basic psychological needs. Participants disclosed that one exercise "…on the first day when I did it, it really hurt when I did it" (P3) and therefore disengaged with the activity for the remainder of the intervention period because of feelings of competency. The lack of choice or autonomy during the designed interventions did not support autonomy. Additionally, the lack of adequate challenge appeared to impact enjoyment and engagement P8 stated "It was boring [because] I already know how to do everything we did".

4.4.3 Body composition

No changes in mass were seen pre to post-intervention of both groups cross, despite decreases in fat mass (FM%) and an increase in fat-free mass (FFMkg) pre- to post-intervention (Figure 4-3). FM% increased back towards pre-intervention intervention levels at follow-up; however, 75%CI showed some overall increase in FFMkg in both groups, despite no greater increase in either group. The control group had a greater overall increase in height over the course of the study period (pre-intervention to follow-up and post-intervention to follow-up). Both groups exhibited mean increases in BMI Z-score from post-intervention to follow-up (Figure 4-3).

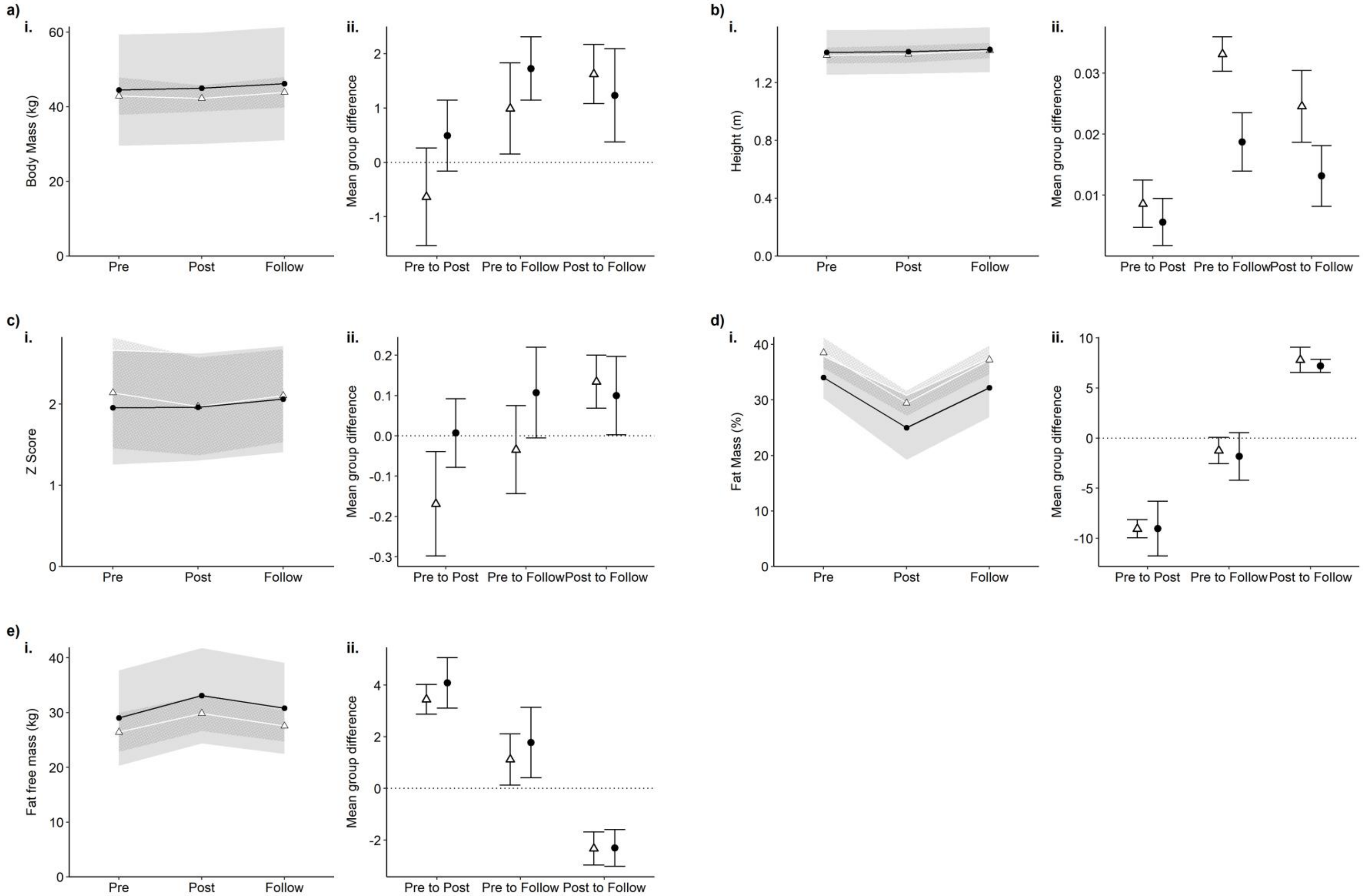

Figure 4-3 (i) pre-intervention, post-intervention and follow-up a) body mass, b) height, c) Z-score, d) fat mass (% of total mass) and, e) fat-free mass (kg) for the experimental group (●) and control group (Δ). (ii) 75% confidence interval mean change between time points for the mean difference between time points.

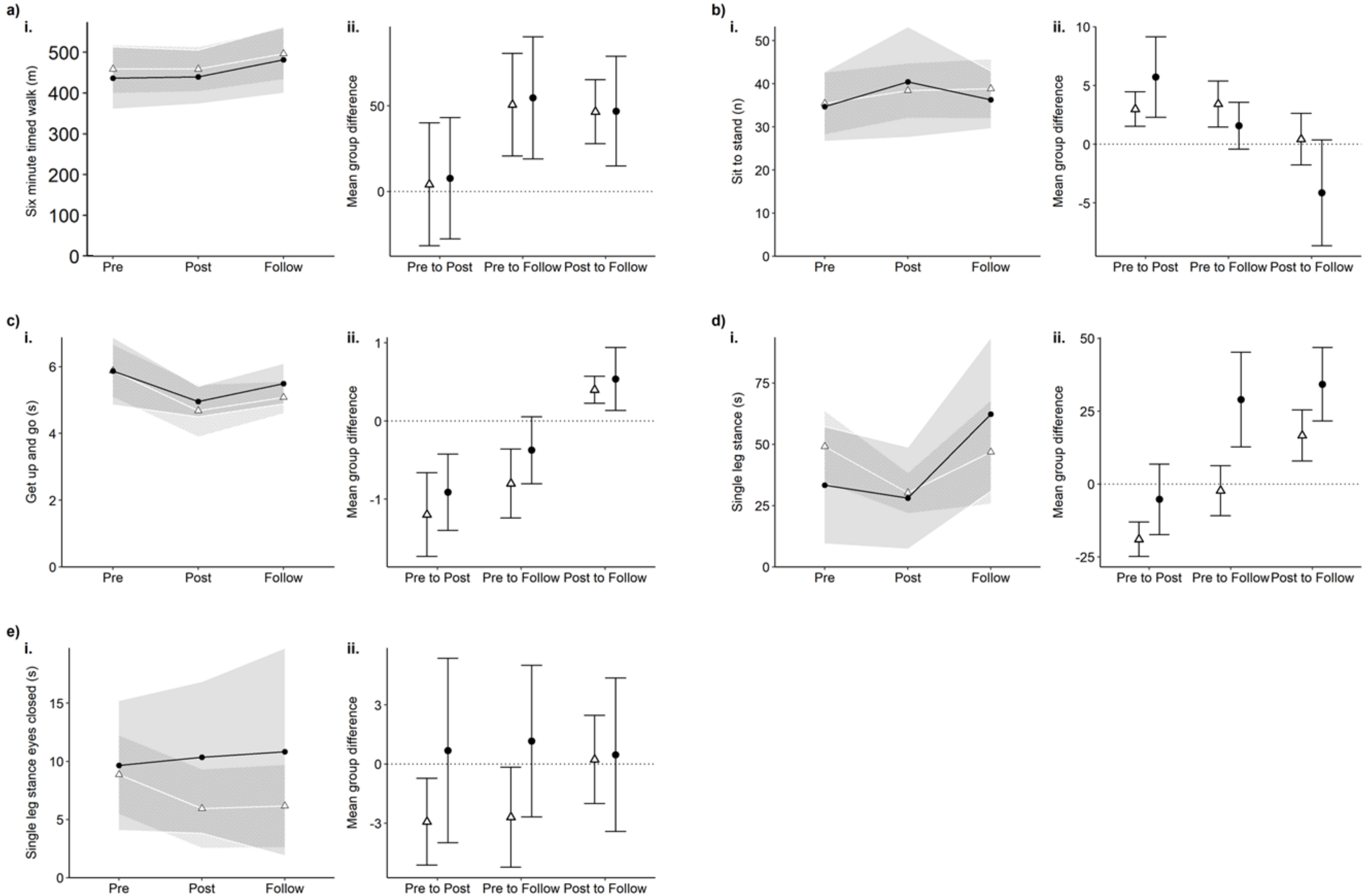

Figure 4-4 (i) pre-intervention, post-intervention and follow-up a) six minute timed walk, b) sit-to-stand, c) get-up-and-go, d) single-leg stance and, e) single leg stance eyes closed for the experimental group (●) and control group (Δ). (ii) 75% confidence interval mean change between time points for the mean difference between time points.

4.4.4 Physical well-being

4.4.4.1 Pain and quality of life

Examination of confidence intervals suggests no change in pain reported now over time or between groups, with mean changes being less than 1mm. The experimental group increased mean reported worst pain in the last 7 days in the follow-up period resulting in an overall increase from pre-intervention, while the control group had a decrease. The control group saw no change in health-related quality of life [HRQoL] across the intervention period. The experimental group saw mean decreases in HRQoL pre- to post and then increased post-to-follow-up, which resulted in no change pre-to-follow-up.

4.4.4.2 Physical activity

Only five participants in the control group and two participants in the experimental group returned their accelerometers with valid data at each time point. The experimental group had a mean increase in the sedentary time pre- to post, with little change in the control group for the same period. Both groups had a decrease in time in sedentary behaviour post-intervention to follow-up, with the control group reducing sedentary behaviour more than the experimental group. There was no mean change in the percent time spent in moderate to vigorous PA (MVPA) pre- to post-intervention for either group. Both groups had a small increase (<5%) of MVPA post-to-follow-up, with the control group showing a greater increase than the intervention group. The control group had small decreases pre to post and increases post to follow up of total vector magnitude counts which evened out to no change pre to follow up. The experimental group showed no change in total magnitude counts over the course of the study period.

4.4.5 Physical function

4.4.5.1 Clinical measures of Physical Function

Both groups had a mean increase in 6MTW distance from post-intervention follow-up with no change pre- to post-intervention. Both groups exhibited an increase in STS performance pre- to post-intervention, which only remained in the control group at follow-up. Both groups showed a decrease in get up and go time, and both groups increased time in the post-to follow-up. However, only the control group managed to maintain an overall increase in performance (less time in timed-up-and-go [TUG]) from pre-intervention to follow-up. The control group saw a decrease in single leg stance (SLS) performance with eyes open from pre- to post-intervention, but this increased in the follow-up period. The experimental group saw a mean increase and an overall greater increase than the control group in SLS eyes open time pre-intervention to follow-up. This increase occurred in the post-intervention to follow-up period, but the increase in this period was not more significant than that of the control group. The control group decreased performance in SLS with eyes closed pre- to post-intervention which was maintained to follow-up. The experimental group maintained SLS with eyes closed performance throughout the study period.

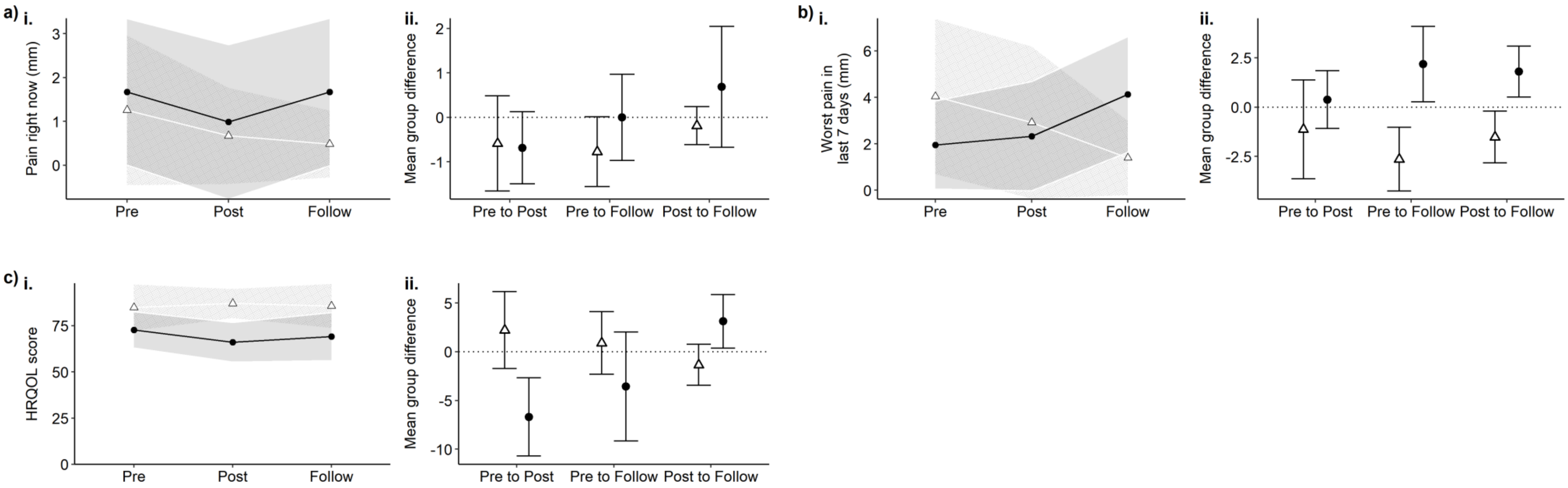

Figure 4-5 (i) pre-intervention, post-intervention and follow-up a) Pain now, b) Worst Pain, c) physical Health Related Quality of Life (HRQoL) for the experimental group (●) and control group (Δ). (ii) 75% confidence interval mean change between time points for the mean difference between time points.

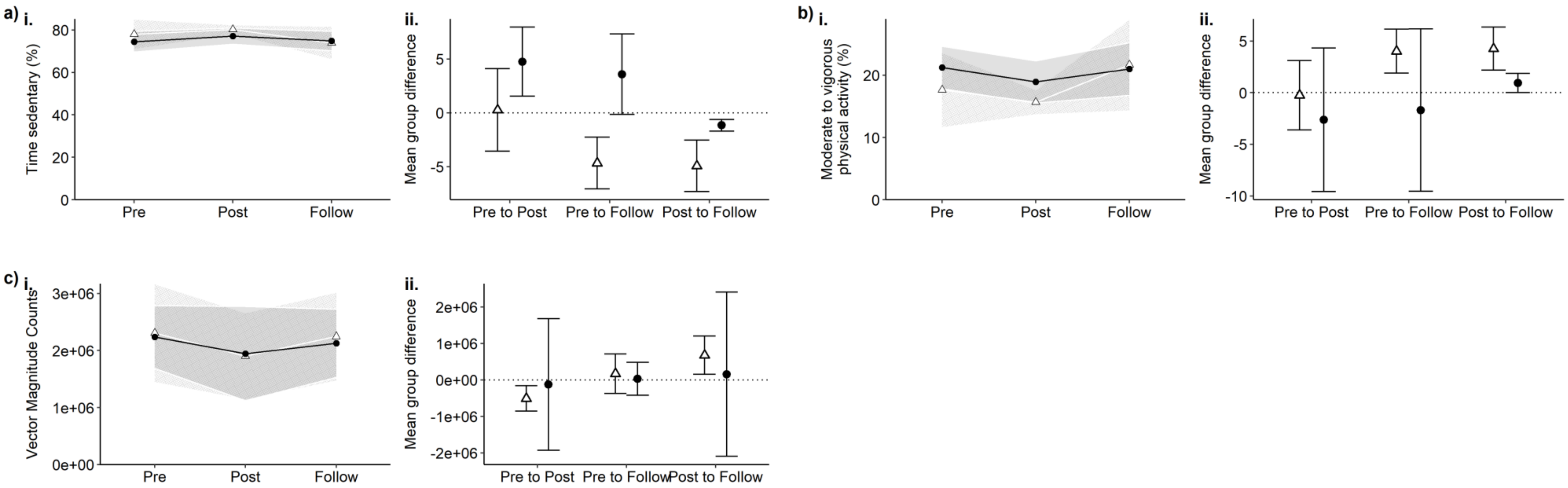

Figure 4-6 (i) pre-intervention, post-intervention and follow-up a) Sedentary time, b) Moderate to Vigorous physical activity, c) Vector magnitude counts for the experimental group (●) and control group (Δ). (ii) 75% confidence interval mean change between time points for the mean difference between time points.

4.4.5.2 Muscular strength

Pre-intervention to post-intervention the experimental group had mean increases in plantar flexion, hip abduction, hip extension, and knee flexion isokinetic strength. Only hip abduction strength in the experimental group saw increases greater than the mean change in the control group. This was maintained for the duration of the follow-up period. The control group had mean decreases in ankle dorsiflexion and hip flexion and increases in ankle plantarflexion.

During the follow-up period, the experimental group saw mean increases in hip adduction, hip extension, knee flexion and knee extension. This resulted in overall (pre to follow-up) mean changes in the experimental group of plantar flexors, hip adductors, hip flexors, hip extension, hip flexion and knee extension. Hip flexion and hip extension were the only muscle groups in the experimental group to have an increase greater than that of the control group. In the follow-up period, the control group only saw a mean increase in knee extensor strength, resulting in this being the only muscle group to have an overall (pre-to-follow) mean change in strength in the control group.

When examining strength relative to body mass, the experimental group saw mean reductions in dorsiflexion and hip flexion isokinetic strength and mean increases in plantarflexion, hip abduction, hip adduction, hip extension, knee flexion and knee extension. The control group exhibited the same changes pre- to post, with no one group having greater changes than the other. In the period post-intervention to follow-up, the experimental group decreased in plantarflexion and hip abduction strength and had mean increases in dorsiflexion, hip adduction, knee flexion, and knee extension with no mean change in hip extension or hip flexion. The control followed the same pattern, resulting in both the experimental and control groups finishing the study stronger relative to body mass in the dorsiflexion, hip abductors, hip adductors, hip extension, knee flexion, and knee extension.

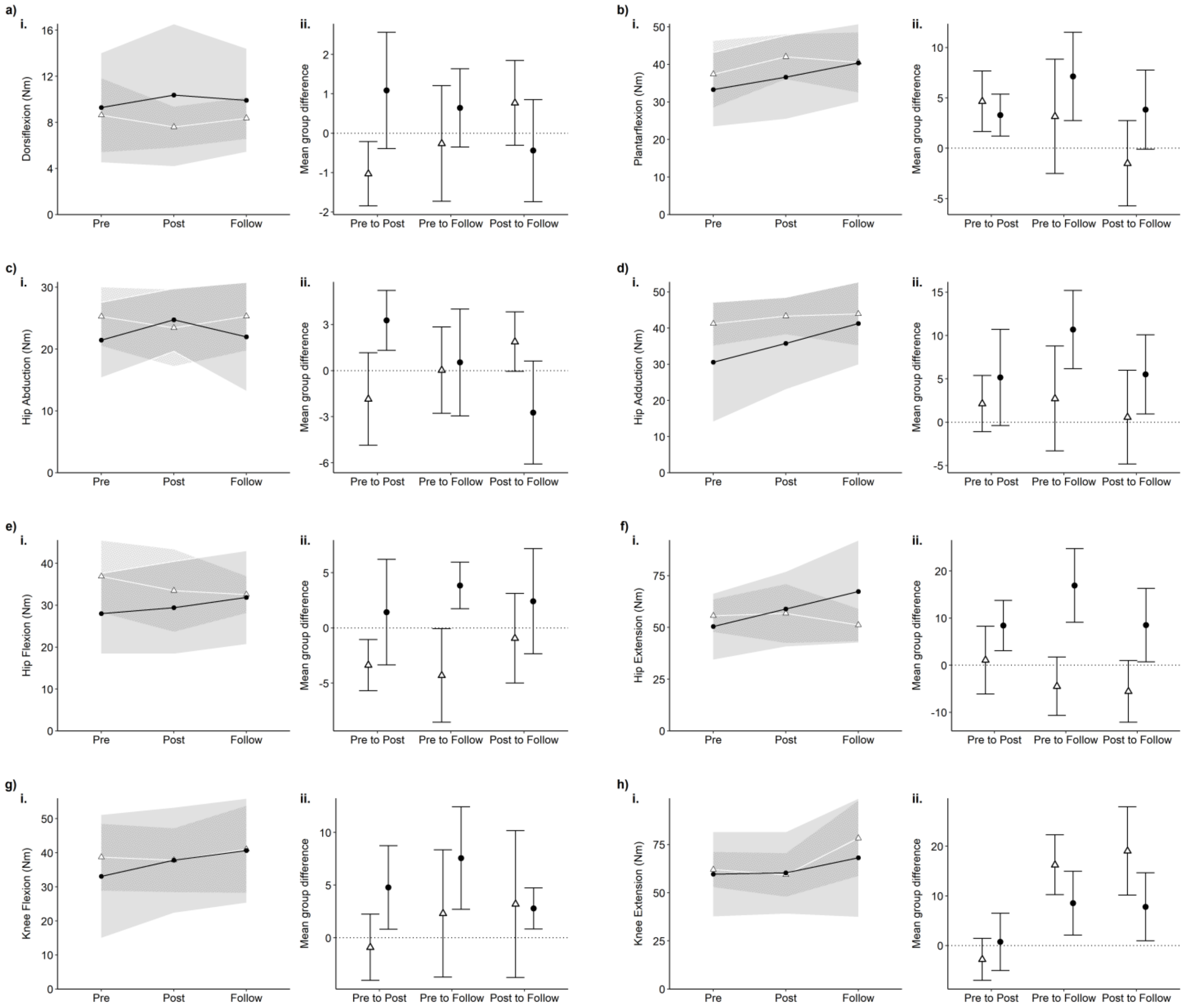

Figure 4-7 4-8 (i) pre-intervention, post-intervention and follow-up a) Ankle plantarflexion, b) Ankle dorsiflexion, c) Hip abduction, d) Hip adduction, e) Hip extension, f) Hip flexion, g) Knee extension, h) Knee flexion (i) for the experimental group (●) and control group (Δ). (ii) 75% confidence interval mean change between time points.

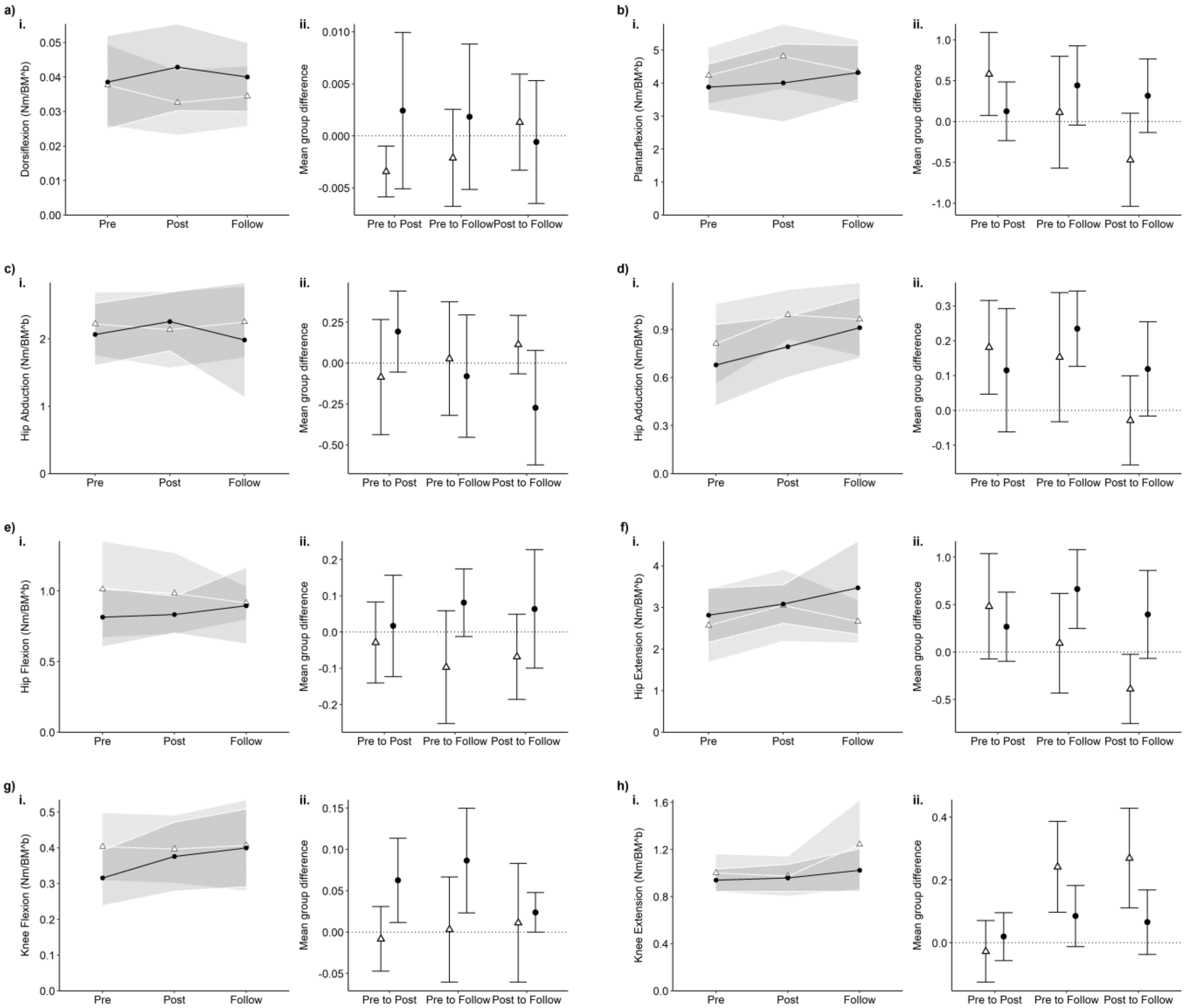

Figure 4-9 (i) pre-intervention, post-intervention and follow-up for allometrically scaled strength a) Ankle plantarflexion, b) Ankle dorsiflexion, c) Hip abduction, d) Hip adduction, e) Hip extension, f) Hip flexion, g) Knee extension, h) Knee flexion (i) for the experimental group (●) and control group (Δ). (ii) 75% (solid) confidence interval mean change between time points.

4.4.6 Centre of mass during single stance phase of gait

There were no mean changes in mediolateral CoM mean velocity during single stance phase of gait (Figure 4-10). The experimental group decreased mediolateral CoM SD velocity post-intervention to follow-up and overall pre-intervention to follow-up, whilst the control group increased. There were no mean changes in mediolateral CoM maximal displacement in the experimental group; the control group demonstrated a decrease in maximal displacement pre-intervention to follow-up.

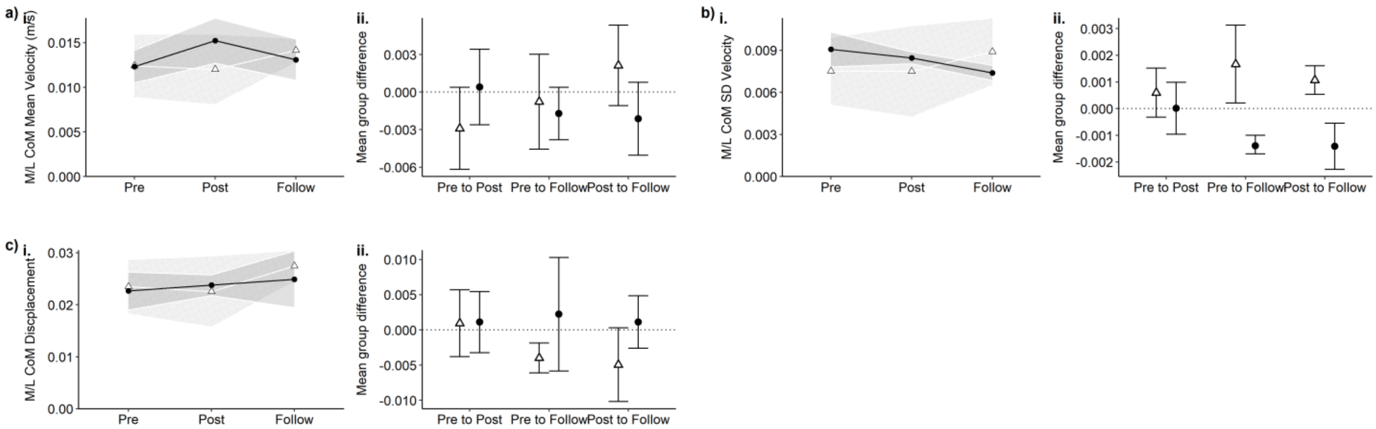

Figure 4-10 (i) pre-intervention, post-intervention and follow-up for the centre of mass during the single stance phase of gait a) Mediolateral centre of mass mean velocity, b) Mediolateral centre of mass standard deviation velocity, c) Mediolateral centre of mass maximal displacement. (i) for the experimental group (●) and control group (Δ). (ii) 75% confidence interval mean change between time points

4.4.7 Temporal-spatial gait parameters

Examination of the 75%CI suggests the control group had an increase in double support time throughout the study period, whilst the experimental group maintained double support time. The experimental group had an increase in stride length pre- to post-intervention that was maintained during the follow-up period. The control group had a decreased gait velocity pre-to-post, which increased again during the follow-up period, resulting in no overall change pre-to-follow. No differences were found in stance phase time across the study period. The experimental group exhibited a decrease in step width during the follow-up, with no change in the control group

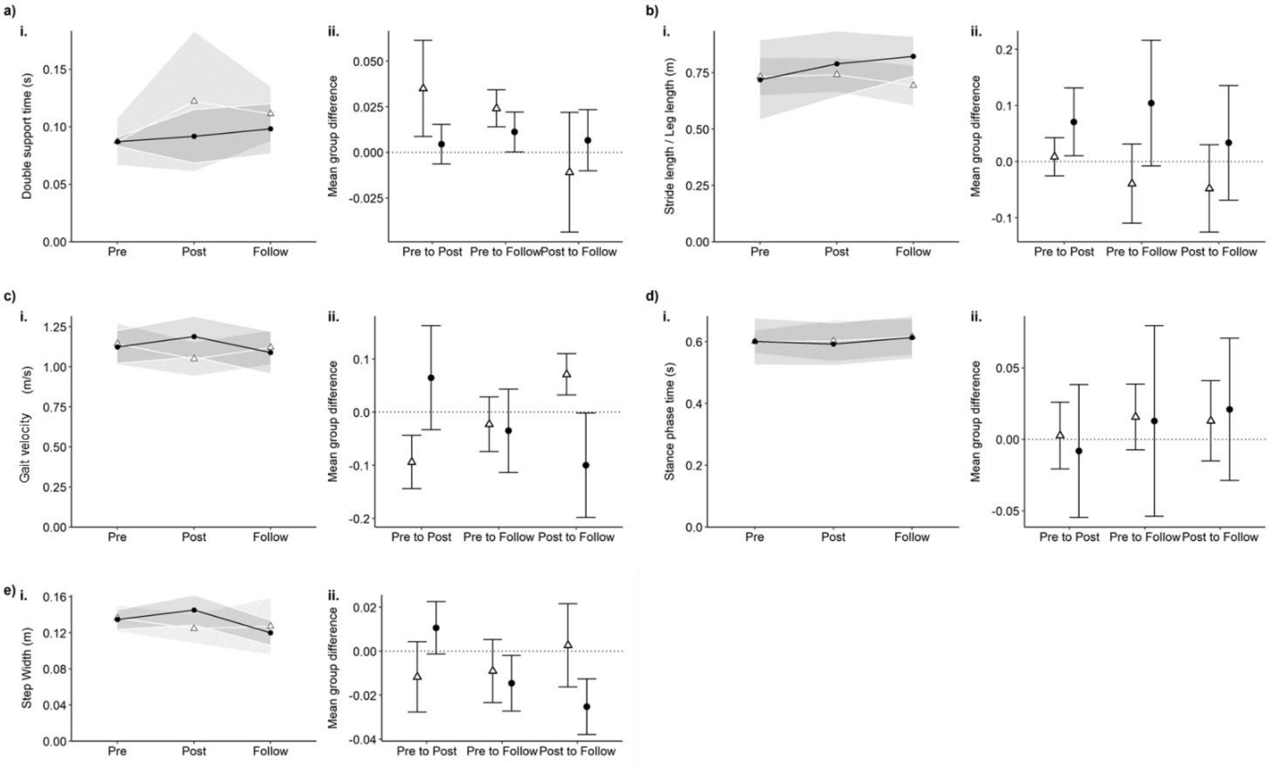

Figure 4-11 (i) pre-intervention, post-intervention and follow-up a) Double support time, b) Stride length/leg length, c) Gait velocity, and d) stance phase time for the experimental group (●) and control group (Δ). (ii) 75% confidence interval mean change between time points.

4.4.8 3D Gait foot kinematics

There were no changes in 3D foot kinematics between groups. Mean changes exhibited from 75%CI between time points revealed changes in both experimental and control groups (Table 4-4, 4-5 and 4-6). Both groups became more dorsiflexed in shank to calcaneus angle during the stance phase (Figure 4-11). Frontal calcaneus to midfoot angle in the experimental fluctuated in abduction between time points (Figure 4-12). Additionally, midfoot dorsiflexion increased in the experimental group at the end of stance at follow-up. The control group exhibited greater external rotation of the midfoot throughout stance at follow-up relative to post-intervention. In midfoot to metatarsal angle the experimental group became more abducted post-intervention. The control group metatarsals were less internally rotated post-intervention and follow-up. Both the control group and experimental group exhibited greater midfoot to metatarsal plantarflexion throughout the stance phase post-intervention and follow-up (Figure 4-13).

Table 4-4 Mean group changes in Shank to Calcaneus angle as identified from 75%CI.

Joint	Plane	Group	Change between time points	%stance	Direction of change
Shank to Calcaneus	Sagittal	Experimental	Pre-intervention to Follow-up	36-82	More dorsiflexed
		Control	Pre-intervention to Follow-up	0-100	More dorsiflexed
		Control	Post-intervention to Follow-up	0-9	More dorsiflexed
		Control	Post-intervention to Follow-up	15-47	More dorsiflexed
		Control	Post-intervention to Follow-up	87-100	More dorsiflexed

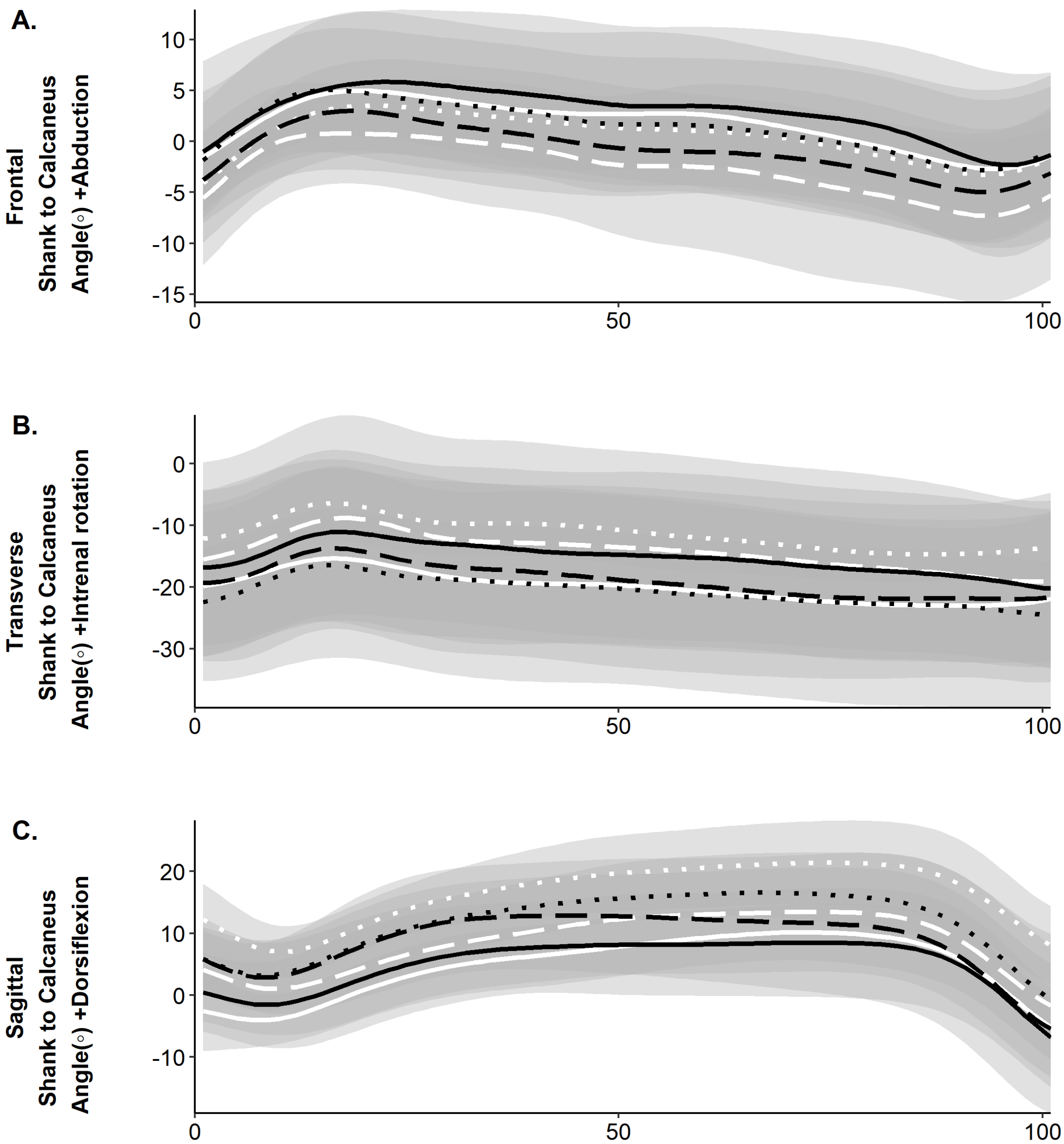

Figure 4-12 Shank to calcaneus angle during stance phase for the experimental and control group, pre-, post-intervention and follow-up. A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line.

Table 4-5 Mean group changes in Calcaneus to Midfoot angle as identified from 75%CI.

Joint	Plane	Group	Change between time points	%stance	Direction of change
Calcaneus to Midfoot	Frontal	Experimental	Pre-intervention to Post-intervention	0-58	Less adducted
		Experimental	Post-intervention to Follow-up	0-100	More abducted
Calcaneus to Midfoot	Transverse	Control	Post-intervention to Follow-up	0-100	More external rotation

Calcaneus to Midfoot	Sagittal	Experimental	Post-intervention to Follow-up	83-100	More dorsiflexed

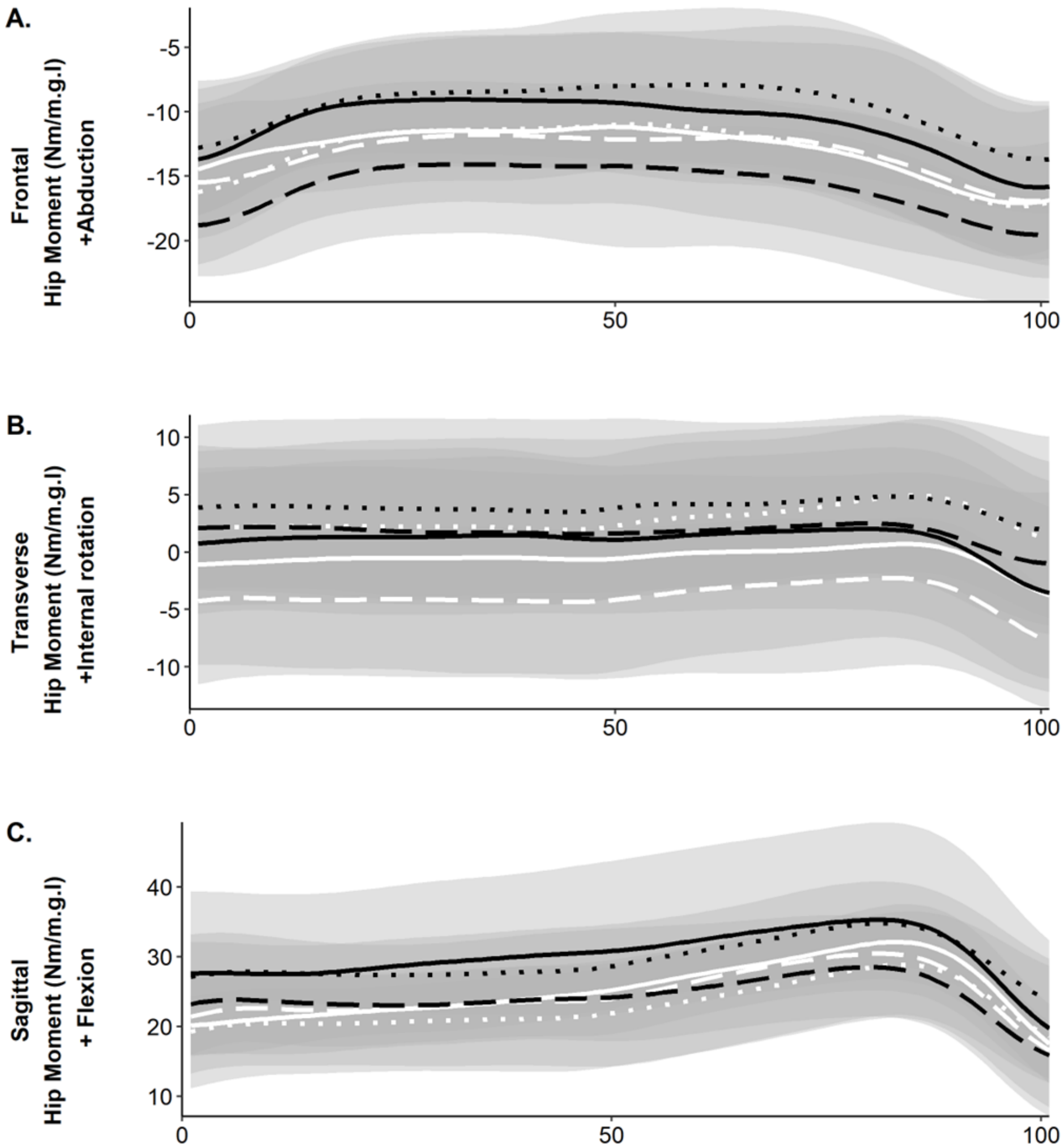

Figure 4-13 Calcaneus to midfoot angle during stance phase for the experimental and control group, pre-, post-intervention and follow-up. A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line.

Table 4-6 Mean group changes in Midfoot to metatarsal angle as identified from 75%CI.

Joint	Plane	Group	Change between time points	%stance	Direction of change
Midfoot to Metatarsal	Frontal	Experimental	Pre- to Post-intervention	0-80	More abducted
		Experimental	Pre- to Post-intervention	90-100	More abducted
	Transverse	Control	Pre- to Post-intervention	0-100	Less internally rotated
		Control	Post-intervention to Follow-up	0-100	Less internally rotated

Sagittal	Experimental	Pre- to Post-intervention	0-100	More plantarflexed
	Experimental	Pre-intervention to Follow-up	0-100	More plantarflexed
	Control	Pre- to Post-intervention	0-100	More plantarflexed
	Control	Pre-intervention to Follow-up	0-100	More plantarflexed

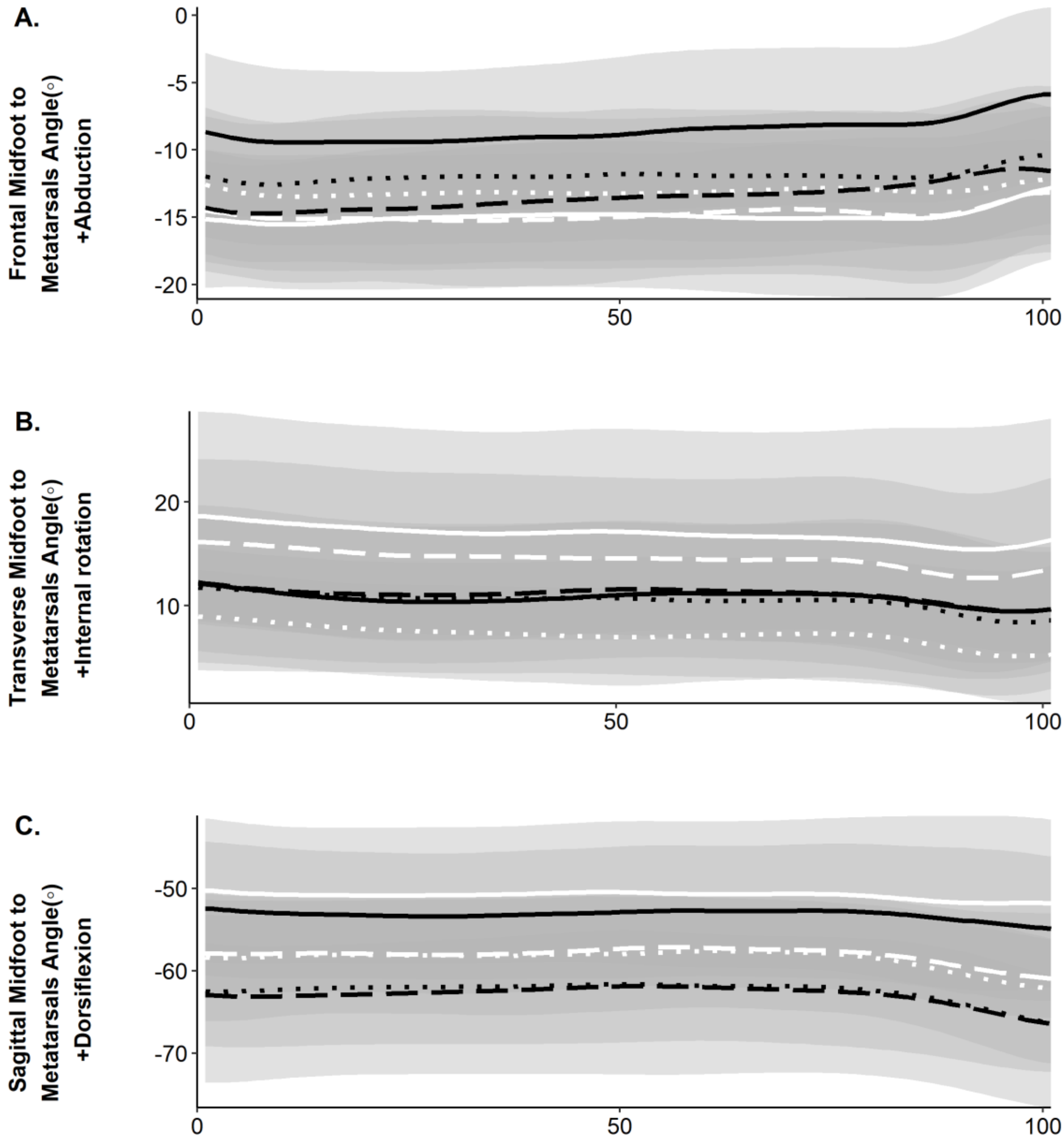

Figure 4-14 Midfoot to metatarsal angle during stance phase for the experimental and control group, pre-, post-intervention and follow-up. A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line.

4.4.9 3D Lower limb kinematics

There were no changes in 3D lower limb kinematics between groups. No changes were exhibited over time for either group for ankle angle during stance (Figure 4-14). Mean changes exhibited from 75%CI between time points revealed changes in both experimental at the knee and control group and the hip (Table 4-7 and 4-8, respectively). The experimental group exhibited more knee abduction during stance at post-intervention compared to pre (Figure 4-15). The control group exhibited more hip abduction and less hip external rotation whilst showing fluctuations in hip flexion throughout stance and over the course of the study period (Figure 4-16).

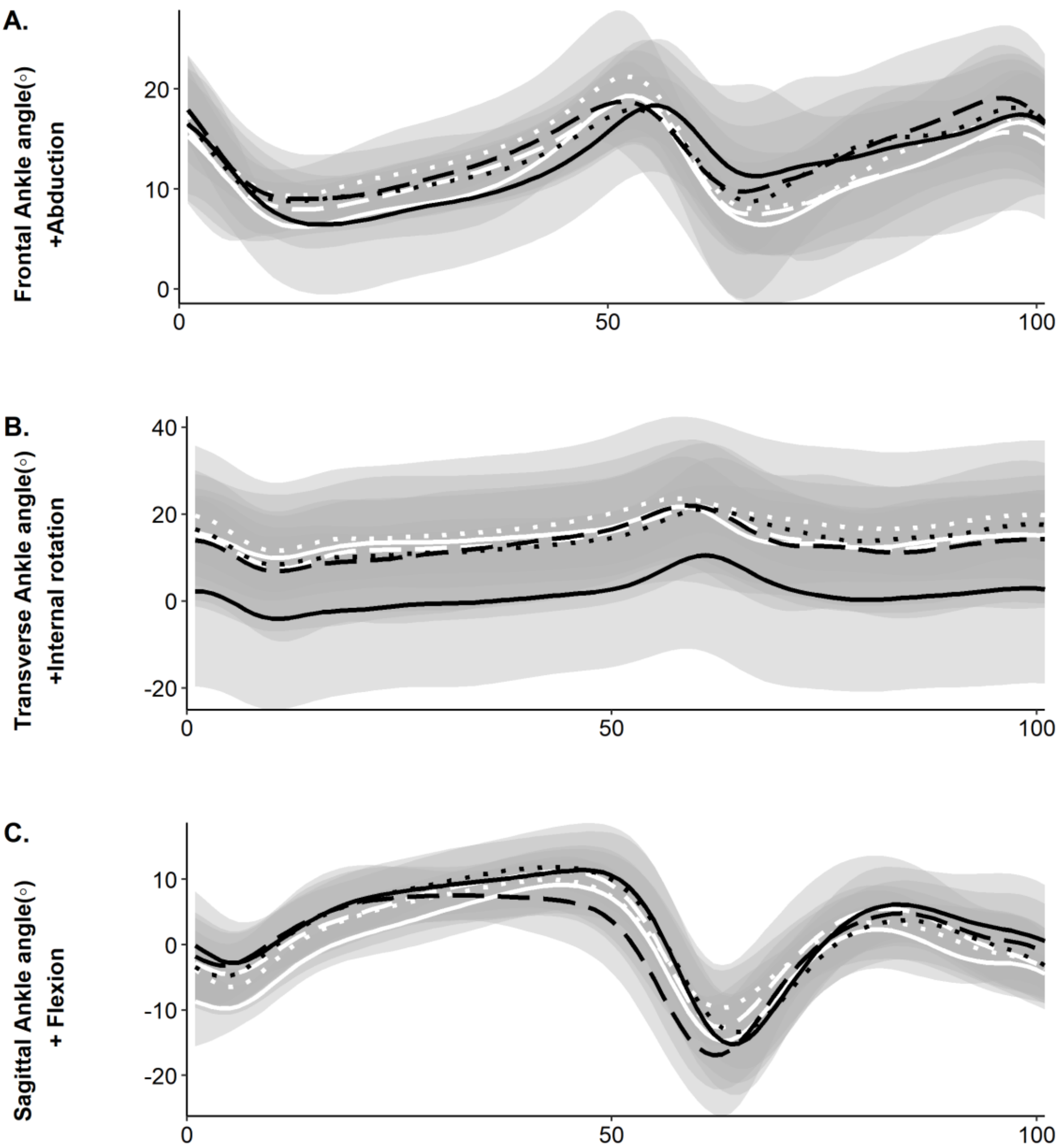

Figure 4-15 Ankle angle during stance phase for the experimental and control group, pre-, post-intervention and follow-up. A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line.

Table 4-7 Mean group changes in knee angle as identified from 75%CI.

Joint	Plane	Group	Change between time points	%stance	Direction of change
Knee Angle	Frontal	Experimental	Pre- to Post-intervention	57-65	More abduction

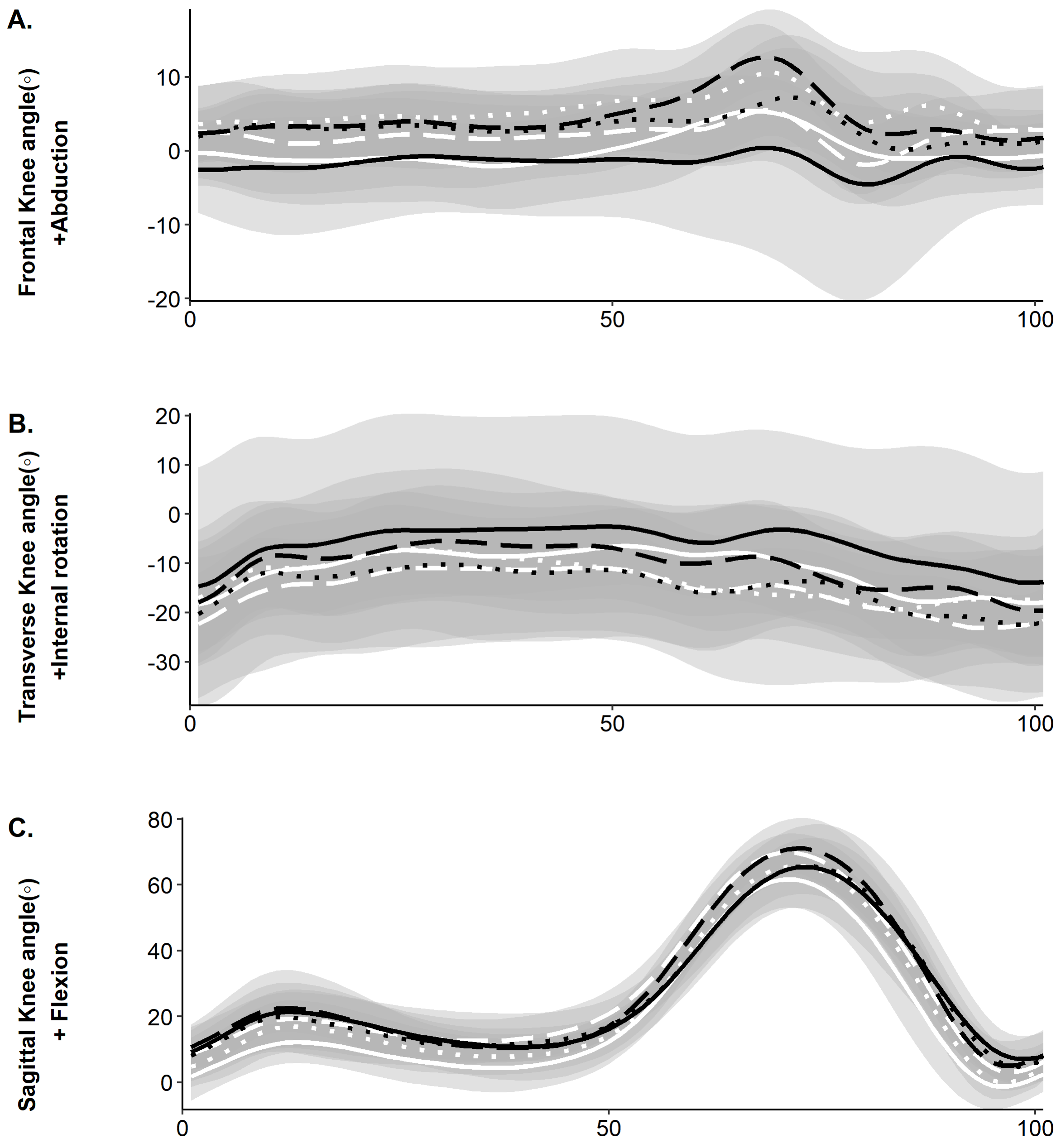

Figure 4-16 Knee angle during stance phase for the experimental and control group, pre-, post-intervention and follow-up. A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line.

Table 4-8 Mean group changes in hip angle as identified from 75%CI.

Joint	Plane	Group	Change between time points	%stance	Direction of change
Hip Angle	Frontal	Control	Pre-intervention to Follow-up	97-100	More abducted
	Transverse	Control	Pre- to Post-intervention	0-6	Less externally rotated
			Pre- to Post-intervention	55-65	Less externally rotated
			Pre- to Post-intervention	72-100	Less externally rotated
		Control	Post-intervention to Follow-up	0-9	More externally rotated
		Control	Post-intervention to Follow-up	83-100	More externally rotated
	Sagittal	Control	Pre- to Post-intervention	0-93	More hip flexion
		Control	Post-intervention to Follow-up	0-6	Less hip flexion
		Control	Post-intervention to Follow-up	22-29	Less hip flexion
		Control	Post-intervention to Follow-up	80-96	Less hip flexion

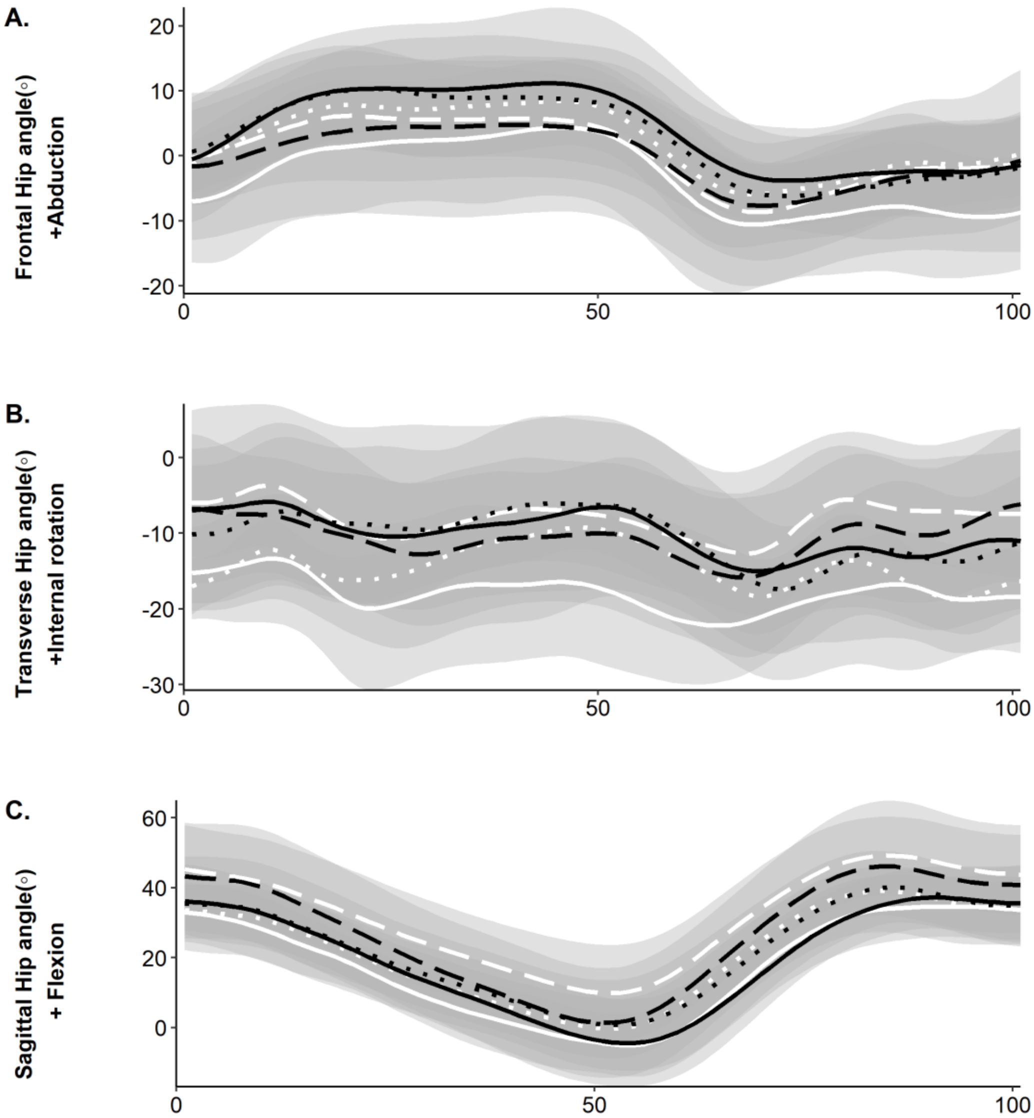

Figure 4-17 Hip angle during stance phase for the experimental and control group, pre-, post-intervention and follow-up. A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line.

4.4.10 3D Lower limb gait kinetics

There were no changes in 3D lower limb kinetics between groups. Mean changes identified from 75%CI between time points revealed changes in both experimental and control groups for a joint moment (Table 4-9. 4-10 and, 4-11) and power (Table 4-12, 4-13 and 4-14). The experimental group exhibited more ankle abduction moment whilst the control group exhibited less ankle abduction moment during stance (Figure 4-17). Additionally, the experimental group had less ankle external rotation moment at the end of stance at follow-up and less ankle flexion moment at the end of stance post-intervention. Mean group changes in knee moment were found at the beginning of stance for both groups. The experimental group showed less knee abduction moment at follow-up. The control group showed an increase in external knee rotation moment at follow-up (Figure 4-18). Changes in hip moment were found only in the control group with increased hip adduction moment and fluctuations in sagittal plane moment across stance phase pre- to post-intervention (Figure 4-19).

Ankle power absorption and generation increased in the experimental group in the frontal and transverse plane at follow-up (Figure 4-20). The control group exhibited an increase in sagittal ankle power generation at follow-up. The experimental group reduced frontal knee power absorption post-intervention to follow-up and increased transverse knee power absorption at the end of stance pre-to post-intervention. The control group exhibited increased transverse knee power in early midstance post-intervention to follow-up (Figure 4-21). Mean group changes over time in hip power were found only in the sagittal plane. The experimental group increased sagittal hip power generation pre-intervention to post-intervention. Similarly, the control group increased sagittal hip power generation from pre-intervention to post-intervention, but this change was reversed to follow-up (Figure 4-22).

Table 4-9 Mean group changes in ankle moment as identified from 75%CI.

Joint	Plane	Group	Change between time points	%stance	Direction of change
Ankle Moment	Frontal	Control	Pre- to Post-intervention	15-24	Less abduction moment
		Experimental	Pre-intervention to Follow-up	0-12	More abduction moment
		Experimental	Post-intervention to Follow-up	17-24	More abduction moment
	Transverse	Experimental	Pre-intervention to Follow-up	85-100	Less external rotation moment
		Control	Pre- to Post-intervention	0-1	More external rotation moment
	Sagittal	Experimental	Pre- to Post-intervention	95-99	Less flexion moment

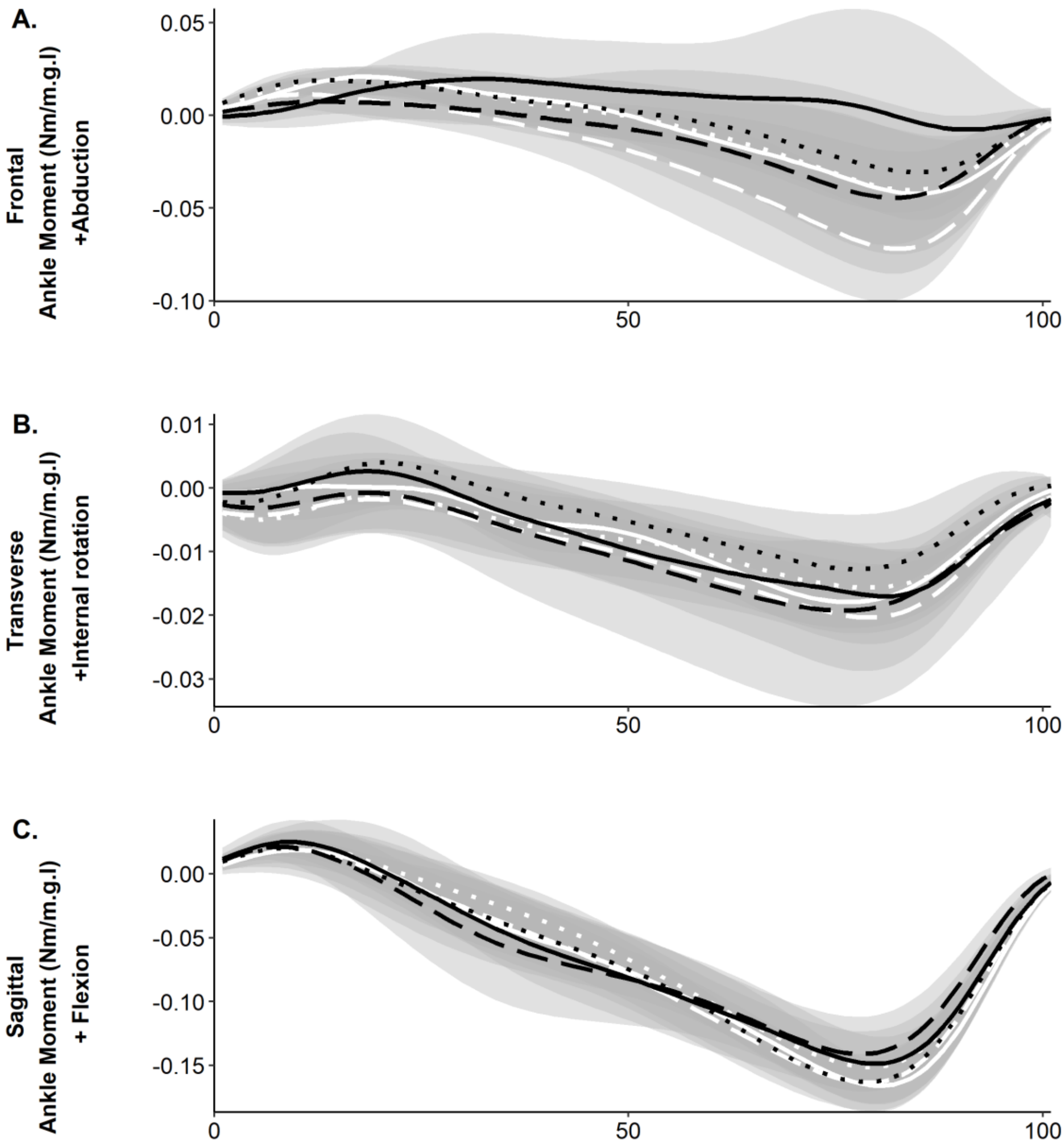

Figure 4-18 Ankle moment during stance phase for the experimental and control group, pre-, post-intervention and follow-up. A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line.

Table 4-10 Mean group changes in knee moment as identified from 75%CI.

Joint	Plane	Group	Change between time points	%stance	Direction of change
Knee Moment	Frontal	Experimental	Post-intervention to Follow-up	2-3	Less abduction moment
		Experimental	Pre-intervention to Follow-up	2-8	Less abduction moment
	Transverse	Control	Pre-intervention to Follow-up	1-2	Greater external rotation moment

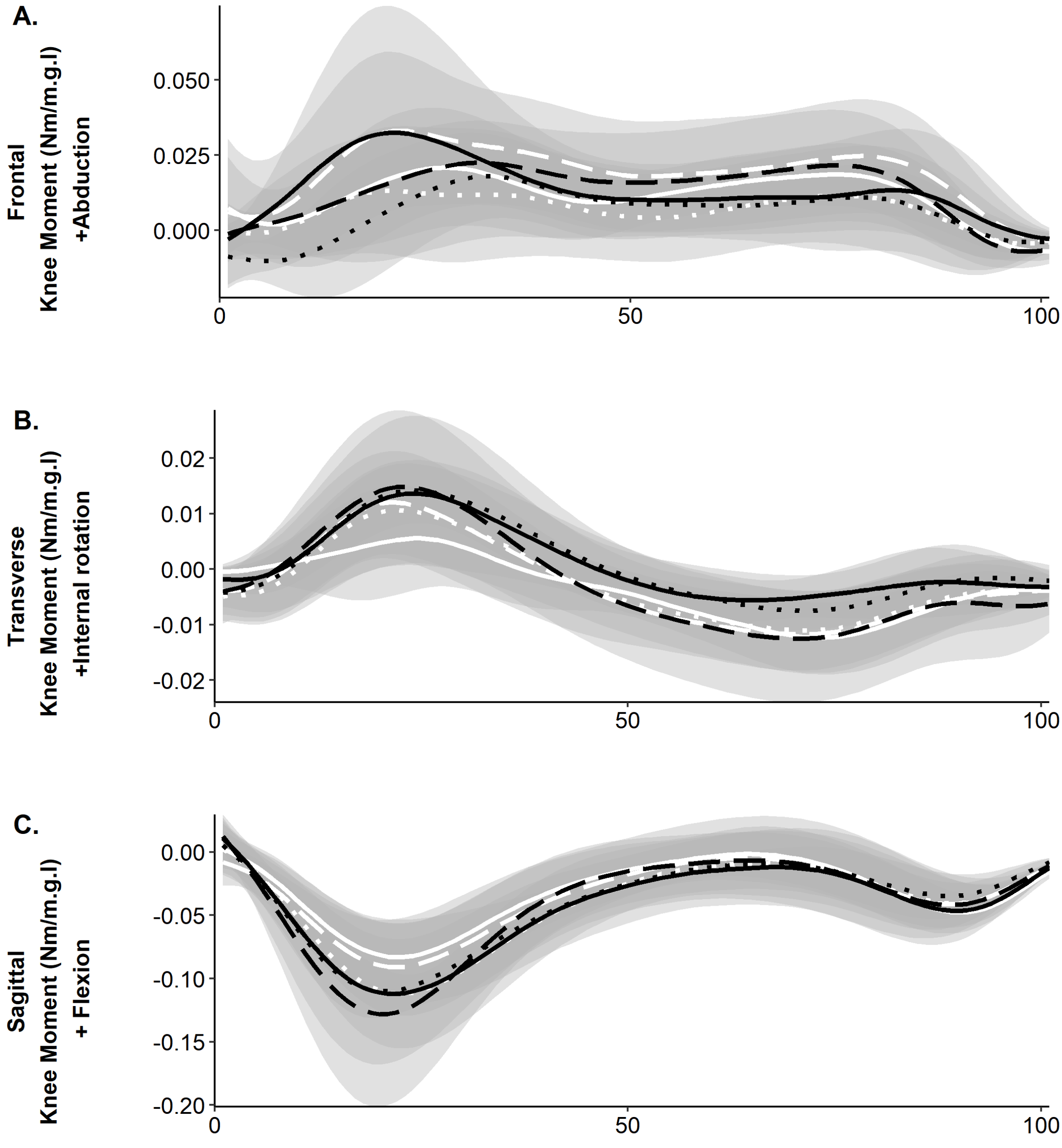

Figure 4-19 Knee moment during stance phase for the experimental and control group, pre-, post-intervention and follow-up. A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line.

Table 4-11 Mean group changes in hip moment as identified from 75%CI.

Joint	Plane	Group	Change between time points	%stance	Direction of change
Hip Moment	Frontal	Control	Pre-intervention to Follow-up	9-13	Greater hip adduction moment
	Sagittal	Control	Pre- to Post-intervention	7-12	Greater hip extension moment
		Control	Pre- to Post-intervention	23-34	Greater hip extension moment
		Control	Pre- to Post-intervention	51-98	Less flexion moment
		Control	Post-intervention to Follow-up	28-94	Less hip extension moment

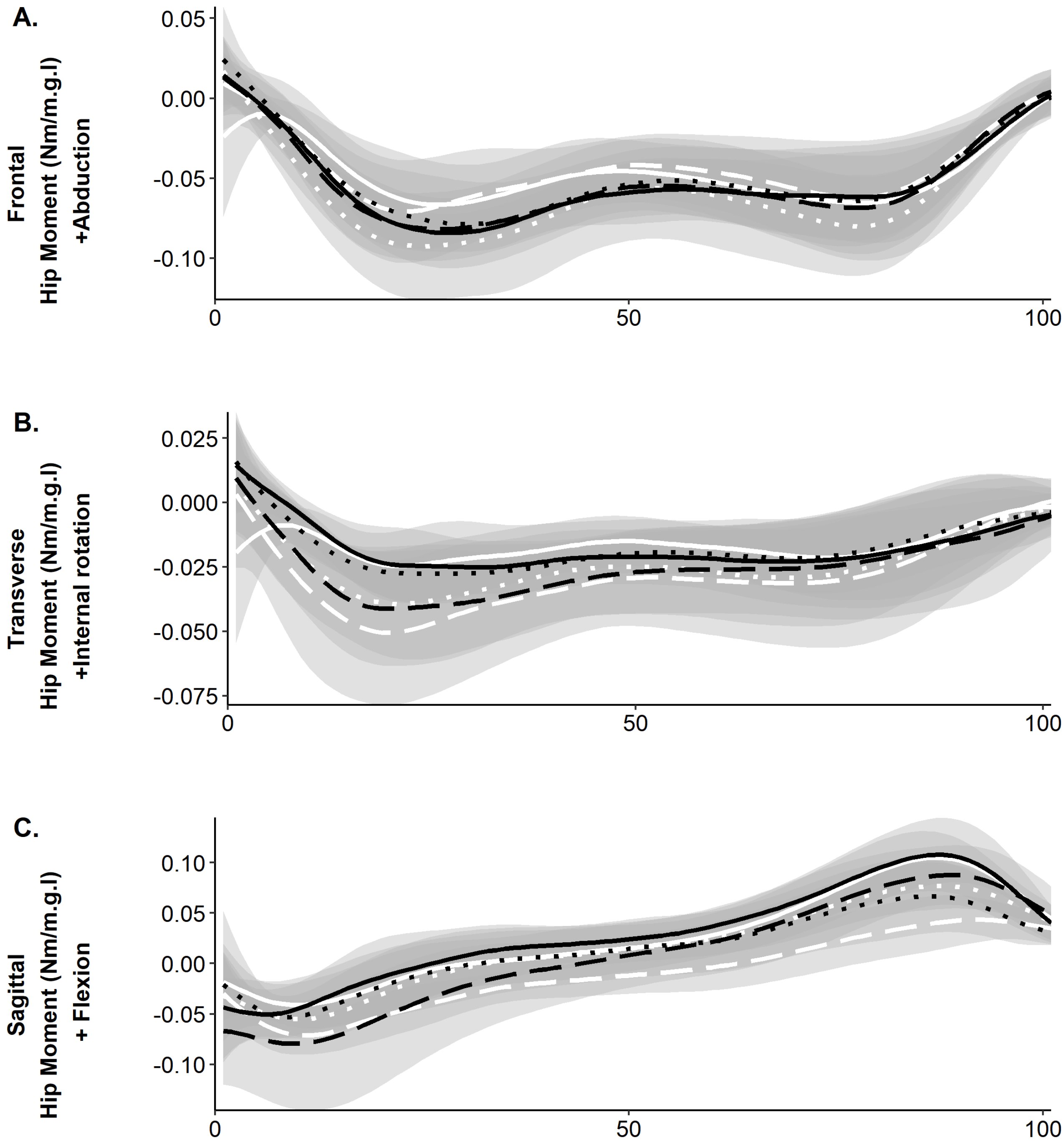

Figure 4-20 Hip moment during stance phase for the experimental and control group, pre-, post-intervention and follow-up. A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line.

Table 4-12 Mean group changes in ankle power as identified from 75%CI.

Joint	Plane	Group	Change between time points	%stance	Direction of change
Ankle Power	Frontal	Experimental	Pre-intervention to Follow-up	3-10	Greater power absorption
	Transverse	Experimental	Post-intervention to Follow-up	33-34	Greater generation
	Sagittal	Control	Post-intervention to Follow-up	11-12	Greater generation

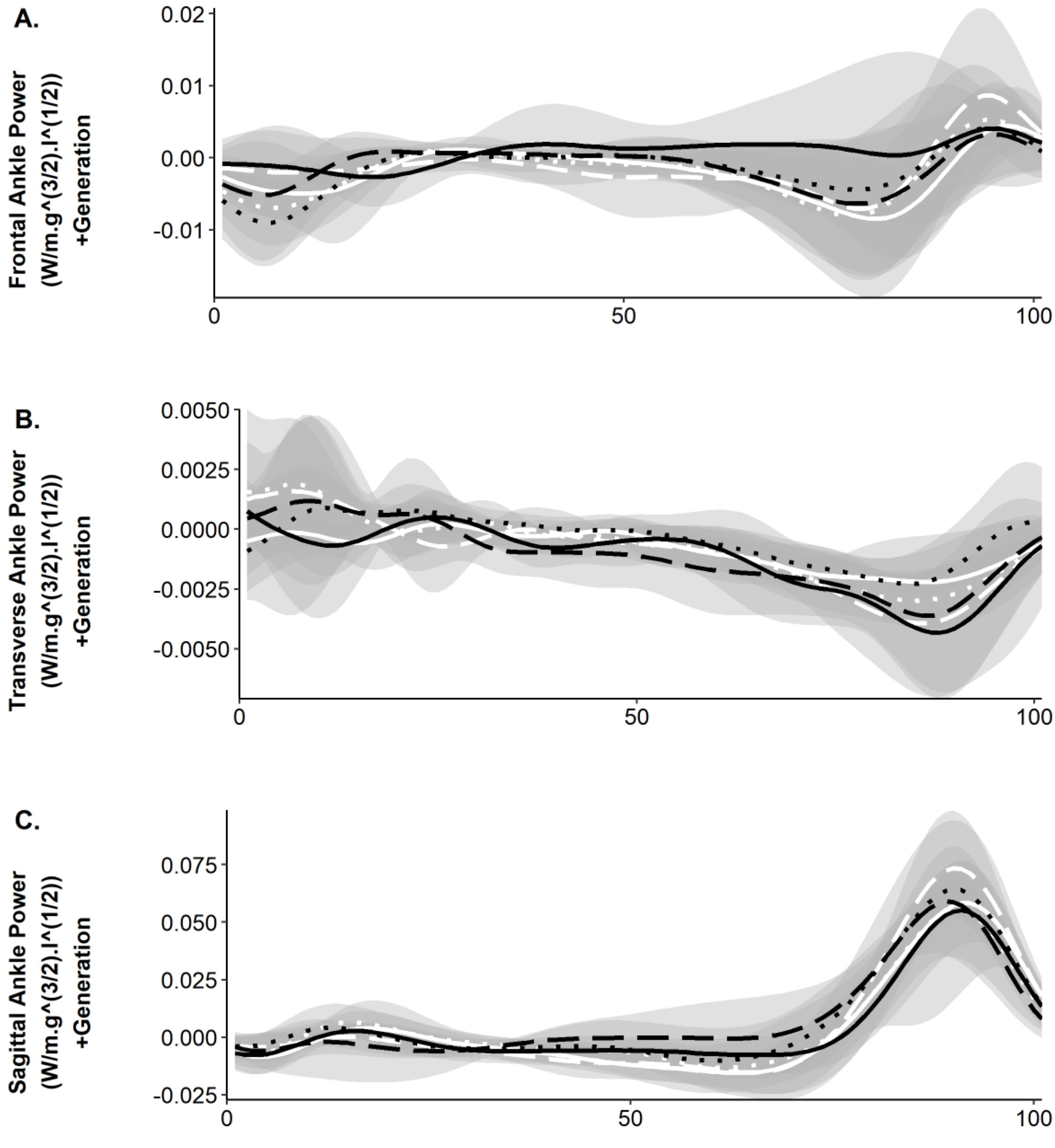

Figure 4-21 Ankle power during stance phase for the experimental and control group, pre-, post-intervention and follow-up. A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line.

Table 4-13 Mean group changes in knee power as identified from 75%CI.

Joint	Plane	Group	Change between time points	%stance	Direction of change
Knee Power	Frontal	Experimental	Pre- to Post-intervention	73-78	Less power absorption
		Experimental	Pre-intervention to Follow-up	72-77	Less power absorption
	Transverse	Experimental	Pre- to Post-intervention	91-92	More power absorption
		Control	Pre-intervention to Follow-up	13-16	More power absorption

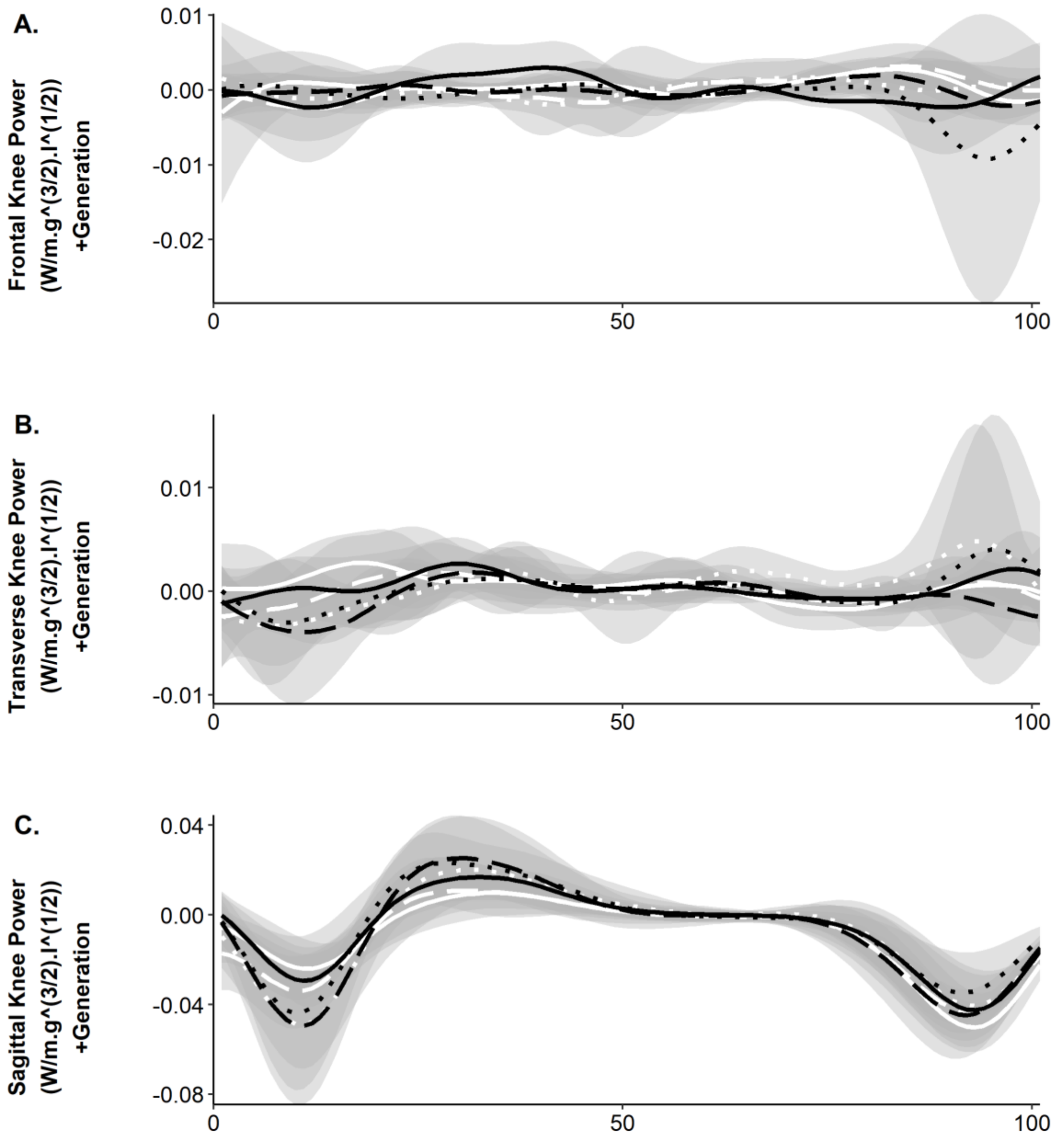

Figure 4-22 Knee power during stance phase for the experimental and control group, pre-, post-intervention and follow-up. A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line.

Table 4-14 Mean group changes in hip power as identified from 75%CI.

Joint	Plane	Group	Change between time points	%stance	Direction of change
Hip Power	Sagittal	Experimental	Pre- to Post-intervention	69-75	Greater power generation
		Experimental	Pre- to Post-intervention	90-93	Greater power generation
		Control	Pre- to Post-intervention	52-55	Greater power generation
		Control	Pre- to Post-intervention	76-77	Greater power generation
		Control	Post-intervention to Follow-up	53-60	Less power generation

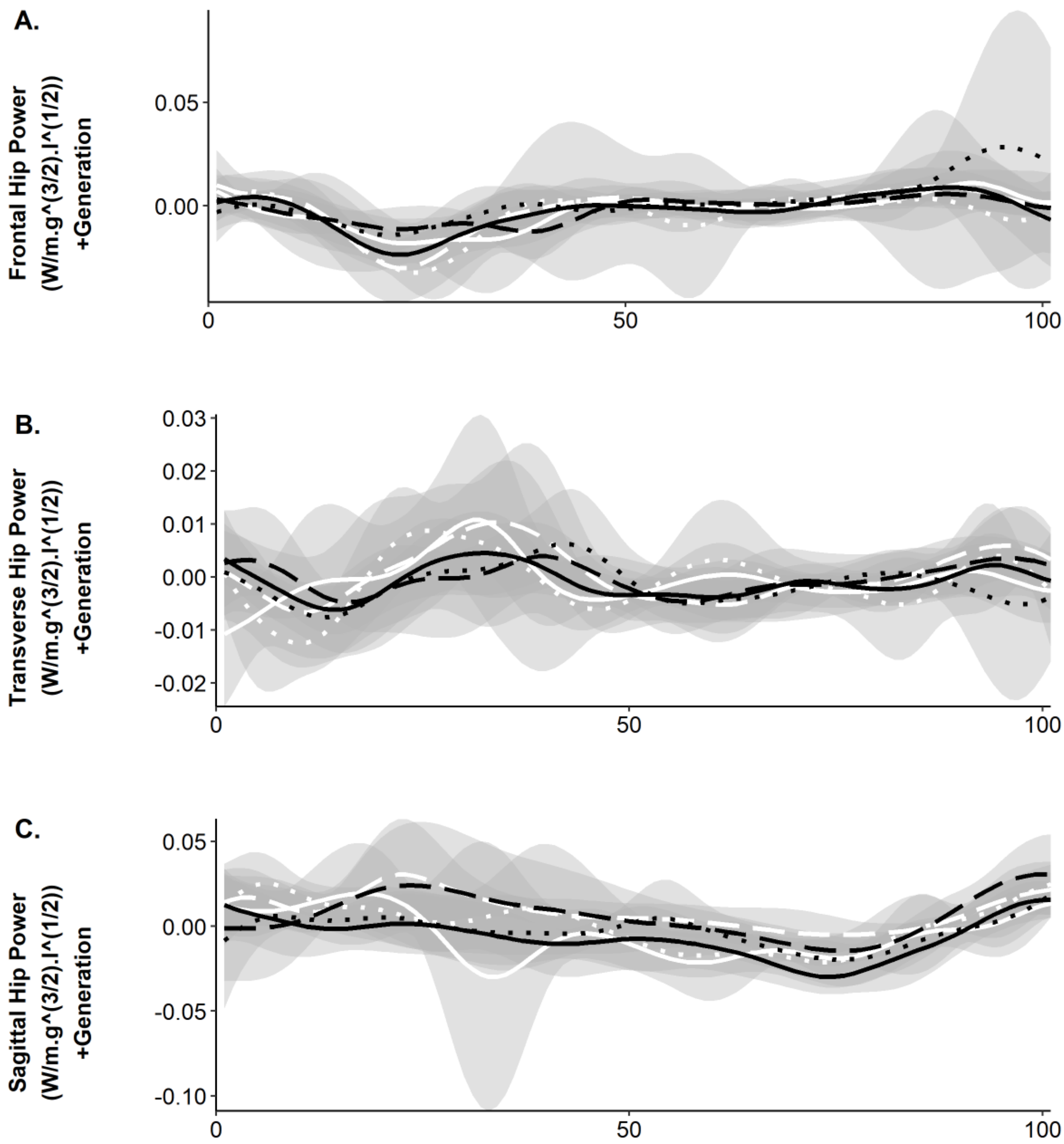

Figure 4-23 Hip power during stance phase for the experimental and control group, pre-, post-intervention and follow-up. A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line.

4.5 Discussion

The aims of this pilot study were to determine the practicalities of implementing an exercise intervention specifically for children with OWB within a school, designed to increase muscular strength and postural stability. Additionally, this study will determine participants' attendance, enjoyment and views of the intervention within the SDT framework. Finally, this study aimed to estimate the effectiveness of the exercise intervention on relative strength, gait kinetics and kinematics, physical function, and physical well-being. Intervention session attendance was largely impacted by participants choosing not to attend sessions. Focus groups determined key areas for intervention development (e.g. session timing, increased novelty and play). As a result of the intervention, there were suggested benefits to SLS performance, increased strength of hip abductors, hip adductors, hip extension and knee flexion in the experimental group. Analysis of gait suggested the experimental group decreased mediolateral CoM SD velocity and step width. Both the experimental and control groups showed changes in foot, knee and hip kinematics, and ankle, knee and hip kinetics during the stance phase.

4.5.1 Attendance and adherence

Average attendance to intervention sessions (73%) failed to meet the >80% attendance thresholds previously set out as beneficial in OWB resistance exercise interventions (Alberga et al., 2013; McGuigan et al., 2009; Treuth et al., 1998). Low attendance poses a significant challenge when considering the application of interventions in real-world settings. For instance, if an 80% minimum attendance threshold had been enforced, 66% of participants would have been excluded from the analysis. While such a threshold could provide information on the effectiveness of the intervention when adhered to, the low attendance rates suggest that, in practice, the intervention's benefits may be minimal if participants do not engage in the sessions. Despite the common application of self-reported exercise logs in child and adolescent exercise interventions, it was noted that participants often falsely reported adherence to sessions in log books (Holt et al., 2020), Future development of this current intervention should look to move to objective measures of adherence and workload to avoid false reporting and improve insights that may be made from such data (Holt et al., 2020).

4.5.2 Basic psychological needs satisfaction and enjoyment.

In the current study, enjoyment was not significantly associated with attendance. The subscale of competency satisfaction was the only BPN significantly associated with attendance, with those who reported greater feelings of competency choosing to attend fewer sessions. As discussed in Section 1.4.2.3, feelings of competency include the need to be adequately challenged to improve motivation quality. The lack of adequate challenge was also discussed during focus group feedback (Section 4.3.2.3). Therefore, it is possible that those participants who reported greater feelings of competency did not feel adequately challenged during intervention sessions and, therefore, were not motivated to attend.

4.5.3 Focus group feedback

The findings from the focus groups highlight that the timing of intervention sessions during children's lunch break impacted attendance, as this time in the day is highly valued by participants as their free time. Many participants viewed lunchtime as an opportunity to engage in activities of their choice, and play is seen as a time without adult control (Brockman et al., 2011). The desire to choose their own activity was particularly strong among male participants, many of whom expressed a preference for playing football over attending the intervention sessions, which they perceived to be a "waste of break.". While the sessions did offer an alternative form of PA for children who would not typically choose traditional playground games such as football, their appeal was largely dependent on the involvement of friends. The inclusion of friends may demonstrate the need for classmate-relatedness. However, relatedness was not discussed in focus groups, and this may need to be further investigated. These findings suggest that future exercise interventions should avoid scheduling sessions during this free period or adopt strategies to better align with students' preferences and social dynamics, thereby enhancing engagement.

The focus group findings highlight children's differing perceptions of activity during play and activity done as exercise, which aligns with Alexander et al. (2014)'s observation that children view these as separate concepts. Any activity that is not perceived as play will likely lack the intrinsic motivation and enjoyment that children associate with play (Alexander et al., 2014a). Conversely, some participants suggested the use of traditional gym equipment, such as dumbbells, as a way to improve the sessions. Such equipment would be associated with traditional perceptions of exercise. Therefore, this preference likely reflects a desire for novelty. Fernández-Espínola et al. (2020) demonstrated the importance of satisfaction of novelty to support autonomous types of motivation, in conjunction with already established BPN. These findings suggest that future interventions should move beyond rigid, exercise-focused approaches and instead integrate elements of novelty and play to better align with children's preferences and foster intrinsic motivation.

Lastly, the focus group findings highlight that amotivation to engage with the intervention was influenced by a combination of physical discomfort, lack of autonomy, and insufficient challenge, all of which contributed to the thwarting of BPN. For example, one participant did not complete Nordic hamstring curls for the remainder of the intervention after feeling discomfort on the first try, illustrating how pain can act as a significant barrier to participation. This aligns with Holt et al. (2020) who reported pain to be a barrier for children and adolescents with MSK disorders to adhere to exercise interventions. The current intervention should be developed to accommodate children who are less active and may already experience some MSK pain. The intervention's controlling environment (compared to an autonomous supportive environment) provided little opportunity to support autonomy, while the lack of adequate challenge further reduced engagement (as previously discussed in Section 4.5.2).

4.5.4 Body composition

Participants with OWB in the current study had lower body mass, FM%, and FFMkg at baseline compared to similar studies, likely due to recruitment from schools rather than clinical settings (Alberga et al., 2013; Horsak et al., 2019). No significant differences in body composition changes were observed between groups across the intervention and follow-up periods, though natural growth was evident with increases in height and FFMkg. Fluctuations in the control group body mass and BMI Z-scores were possibly influenced by one control participant whose weight classification shifted from obese to overweight during the intervention period, likely due to personal factors rather than a group-wide effect as the control group carried on normal activities.

4.5.5 Physical well-being

The experimental group reported an increase in worst pain in the last 7 days, driven by changes in the follow-up period, while the control group had a decrease. The increase in pain in the experimental group may have implications on the appropriateness of short-term exercise interventions in children with OWB. However, the interrelated mechanisms of OWB and pain (e.g. related joint loading, systemic inflammation and psychological components) and exercise are multifaceted and require further examination (Paley & Johnson, 2016).

The control group saw no change in HRQoL across the intervention period. The experimental group saw mean decreases in physical HRQoL pre- to post and then increased post-to-follow-up, which resulted in no change pre-to-follow-up. Examination of the responses of the PedsQL Paediatric Quality of Life Inventory (Appendix B) used to determine physical HRQoL in the current study revealed that the largest changes in responses from pre-intervention to post-intervention were in question 4 “is hard for you to lift something heavy” (mean change -25 ± 40). Schranz et al. (2013) similarly report that findings from resistance training intervention effects on HRQoL in children and adolescents with OWB do not favour resistance training. It may be that participants in the experimental study have a different perspective on their abilities to lift something (i.e. they then felt less competent) after the intervention, which may have implications for the positive lasting effects of children's PA behaviour.

Mean group changes between time points do not necessarily support the use of the current intervention to improve PA behaviour in children with OWB. However, the poor adherence to accelerometer protocols and returning devices significantly impacts the interpretation of PA results. More needs to be done to ensure protocols are followed and accelerometers returned by all participants.

4.5.6 Physical function

4.5.6.1 Clinical measures of physical function

The current cohort walked less distance during the 6MTW (450.9 ± 45 m) compared to children with OWB in previous studies (571.2 ± 65.5 m), likely due to the shorter track length increasing turning frequency (Morinder, 2009; Pathare & Haskvitz, 2012). However, participants outperformed OWB peers in STS repetitions, TUG, and SLS time, possibly due to the inclusion of younger and less severely obese participants (Nunez-Gaunaurd et al., 2013; Pathare et al., 2013; Tsiros et al., 2012). Increases were found in SLS with eyes open in the experimental group, with no change in the control group, suggesting a positive effect of intervention on static balance ability.

4.5.6.2 Muscular strength

Absolute knee extension strength observed in the current study was lower than that reported in some previous (193.8 to 224.6 Nm, respectively) studies (Abdelmoula et al., 2012; Garcia-Vicencio et al., 2016; Maffiuletti et al., 2008). This difference is likely attributable to the inclusion of adolescents, differing gravity normalisation and varying velocities in those studies. In contrast, absolute strength in the hip, knee, and ankle was slightly higher than the values reported by Theis et al. (2019), who reported in children with OWB 7-11 years, potentially due to the slightly greater body mass and FFMkg of participants in the current study. No significant differences were found between groups in changes in absolute strength from pre- to post-intervention. Examination of the

75% confidence intervals indicates that, potentially with a larger sample size or improved intervention attendance, significant differences might emerge in ankle dorsiflexion, hip abduction, hip adduction, and knee flexion post-intervention. The observed improvements in these muscle groups may be attributed to the positive effects of targeted exercises such as monster walks and the Nordic hamstring exercise. However, certain exercises may require adjustments in volume, intensity, or selection to elicit greater effects in specific muscle groups. Supporting this, Horsak et al. (2019) reported a significant increase in hip abductor strength following a 12-week intervention, while knee extensor strength did not change. The quadriceps, which play a primary role in maintaining knee extension against gravitational force and body mass, may not receive sufficient stimulus from these exercises to improve strength beyond the natural training effect of carrying excess body mass over time. The findings in the current study and from Horsak et al. (2019) suggest that this limitation might be addressed by increasing adherence and, consequently, training volume, which might lead to statistically significant improvements in quadriceps strength.

Normalising strength allometrically to body mass aims to remove the association between strength and body mass. In the current study, power exponents for body mass were larger than those reported in some previous studies (Theis et al., 2019; Tsiros et al., 2013), indicating a steeper slope and a stronger relationship between body mass and strength in this cohort. There were no significant differences between groups in changes to allometrically scaled strength from pre- to post-intervention. Both groups exhibited reductions in strength allometrically scaled to body mass for dorsiflexion, hip flexion, and knee extension despite increases in absolute strength. This suggests a shift in the relationship between body mass and strength. Examination of the 75% confidence intervals indicates a reduction in plantarflexion and hip adduction strength in the experimental group. To enhance strength relative to body mass, future interventions should focus on increasing participant attendance and optimising the design of targeted exercises to improve their effectiveness.

4.5.6.3 CoM during single stance phase of gait

The experimental group showed a decrease in mediolateral CoM SD velocity from post-intervention to follow-up and overall from pre-intervention to follow-up, while the control group exhibited an increase. A decrease in SD velocity suggests a decrease in velocity variability from which increased CoM stability may be inferred. Maximal mediolateral CoM displacement remained unchanged in the experimental group, whereas the control group showed a reduction from pre-intervention to follow-up, suggesting the control group exhibited mechanisms to reduce CoM displacement over time.

4.5.6.4 Temporal-spatial parameters of gait

No significant changes were observed in spatial-temporal gait measures. Double support time is commonly associated with gait stability (Molina-Garcia et al., 2019), while stride distance has shown inconsistent differences between obese and healthy-weight children (Molina-Garcia et al., 2019). Hills and Parker (1992) reported that children with OWB had significantly greater stride lengths than their healthy-weight peers, while Hung and Gill (2013), who adjusted stride length relative to leg length, found significantly shorter stride lengths in children with OWB. D’Hondt et al. (2011) observed shorter stride lengths after vision was removed, indicating a more tentative gait. The current findings suggest that the intervention had no effect on these measures.

4.5.6.5 3D foot kinematics

The midfoot, relative to the calcaneus, showed significantly more plantarflexion in the experimental group from pre- to post-intervention. When this significant change is combined with the 75% confidence intervals, which suggest changes in the metatarsals (more plantarflexed and more inverted during initial contact and midstance), it indicates reduced pronation of the foot, previously associated with greater body fat (Mahaffey et al., 2016). While plantarflexion strength did not increase significantly in the experimental group compared to the control group, it is possible that the strength intervention enhanced foot strength and frontal plane ankle strength, which were not specifically measured in the current study.

4.5.6.6 3D Lower limb kinematics.

During initial contact and the loading phase, the heel strikes the ground, the foot plantarflexes to become flat on the ground, and the limb begins to accept body weight. During this phase, and extending into midstance, the experimental group exhibited a reduction in ankle dorsiflexion angle compared to the control group. Shultz et al. (2009) suggest that a reduction in ankle dorsiflexion increases the time spent in plantarflexion, thereby enhancing propulsion. During this same loading phase, children with OWB often display a straighter (more extended) leg to reduce the workload on the knee extensors against gravity or to compensate for the hip drop on the contralateral side. The experimental group increased knee flexion compared to controls post-intervention during this part of the gait cycle. However, the knee extensor strength of the experimental group did not significantly increase relative to controls in either absolute terms or when normalised to body mass. This indicates that the changes in knee flexion angle at initial contact were not due to strength improvements in the knee extensors.

Once the foot is flat, the body progresses forward over the foot during midstance as the contralateral limb swings forward. During this phase, significant differences between groups were observed in the change in transverse knee angle, and the 75% confidence intervals suggest a possible change in ankle transverse angle in the experimental group as they approached this phase. Children with OWB are known to exhibit increased out-toeing and external rotation of the ankle, with internal rotation of the knee often associated with increased fat mass (Hills et al., 2001; Mahaffey et al., 2018). These opposing rotations in obese children have been linked to excessive flattening and pronation of the foot. In the current study, the experimental group showed a significant increase in ankle internal rotation and knee external rotation, indicating an improvement from the typical adverse transverse plane movements observed in children with OWB. Snook (2001) suggested a relationship between reduced plantarflexion strength and increased foot pronation. However, since no significant increases in plantarflexion strength were observed in the experimental group, it cannot be determined that changes in ankle and foot motion were a result of increased strength around the ankle.

4.5.6.7 3D lower limb kinetics

The control group demonstrated a significant increase in hip abduction moment and a decrease in hip flexion moment during midstance. During the single-leg stance phase, the vertical force vector passes medially, creating an external hip adduction moment. This moment is greater with increased step width and during the stance phase, both of which are strategies often employed to enhance stability in OWB individuals (Morrison et al., 2008). However, these strategies have also been linked to increased thigh girth (Davids et al., 1996;

Shultz, D'Hondt, Fink, et al., 2014). Given the reduction in body mass, greater fat mass reduction, and lower accrual of fat-free mass in the control group, these changes may have translated into reduced thigh girth, requiring a narrower step width and altering the vertical force vector, ultimately leading to a significant increase in hip adduction in the control group.

The control group also exhibited a significant reduction in hip flexion moment during midstance. This internal hip flexion moment is thought to result from a combination of the adductor longus, rectus femoris, and the stretching of ligaments as the hip extends (Levine et al., 2012). Given the reduction in stride length relative to leg length in the control group, there may have been less passive tissue stretch and, consequently, a reduced need for hip flexor contraction. This finding was supported by subsequent changes from post-intervention to follow-up, during which the control group demonstrated a significant increase in stride length relative to leg length, coinciding with a significant increase in hip flexion moment.

OWB children typically exhibit greater power generation and absorption to effectively propel and control a larger mass. Despite no reduction in body mass, the experimental group demonstrated a beneficial change in ankle power absorption post-intervention. Specifically, power absorption was significantly decreased in the ankle evertors after initial contact and in ankle dorsiflexion during midstance. These changes may be attributed to the positive alterations in ankle kinetics discussed earlier and adjustments in the three segments of the foot throughout the gait cycle.

4.5.7 Limitations

The findings on intervention effectiveness on outcome measures are limited due to low participant numbers, low attendance, and low adherence to the intervention. However, the use of 75%CI mitigates this and is suggestive of beneficial findings on hip strength and gait kinetics, and the intervention in the current study provides the foundation for further development. Additionally, some findings of the focus group may be study-specific (e.g. lunchtime and playground setting of some sessions), but framing these findings within SDT theory allows for some generalisability to wider exercise interventions in children with OWB.

4.5.8 Implications

This study demonstrates that school-based interventions are feasible and suggests some beneficial effects on physical function, but the timing of intervention sessions and the content and format of delivery of those sessions is important to participant attendance and adherence. This study provides valuable insights into how children with OWB perceive and engage with a school-based exercise intervention, highlighting key factors that influence feasibility and acceptability. Understanding these perspectives is essential for refining intervention design, ensuring that interventions are both engaging and sustainable. By identifying barriers and facilitators from participants' viewpoints, this work contributes to the development of more tailored and impactful strategies that enhance participation and long-term adherence to exercise interventions.

4.6 Conclusion

The intervention had a beneficial change for the experimental group by increasing absolute hip abduction strength, although increases in the current study are relatively lower than those reported in other studies, and adjusting or adding to this exercise may prove beneficial to further strength increases. The experimental group reduced flattening and pronation of the foot during stance, therefore requiring less power absorption around the ankle. These positive changes at the knee, ankle and foot remained after 3-month follow-up. Whilst changes in hip kinematics for the control group have been attributed to the significant reduction in body mass and relative stride length in this group, and sagittal plane hip moment returned back to baseline values at 3 months follow-up along with stride length. Post-intervention questionnaires and focus groups revealed there were some differences in enjoyment, motivation and reporting of perceived exertion between girls and boys. Adherence to the programme was greatly affected by the timing of sessions, and therefore, future studies should look to minimise the impact on children's free activity time at school. Additionally, enjoyment and interest in the intervention and, therefore, adherence could be increased through the use of equipment deemed as novel to participants. The OMNI RPE scale may require greater explanation and clarity with younger groups as they viewed the ends of the scale in extreme contrast and, therefore, misrepresented actual perceived exertion. A larger study with adjustments to the intervention design is required to build upon the suggested benefits seen in this current small pilot.

This pilot study demonstrated both potential positive effects and challenges of implementing an exercise intervention to improve strength and postural stability within a school setting for children with OWB. While attendance rates were comparable to similar interventions, they fell short of the desired >80% threshold required to maximise effectiveness, with self-reported adherence often misrepresenting actual engagement. These findings underscore the need for objective measures of adherence and workload in future iterations of the intervention. Additionally, participants' feedback revealed that lunchtime scheduling and the lack of autonomy and adequate challenge negatively impacted attendance and enjoyment. Addressing these barriers by rescheduling sessions, incorporating elements of play and novelty, and ensuring activities align with participants' interests and social dynamics may improve adherence and engagement. The intervention showed improved absolute strength and improvements in gait kinetics and kinematics, suggesting a shift away from adverse movement patterns typically associated with children with OWB. These effects were limited by poor adherence and the need for targeted exercise refinement.

Moving forward, interventions should prioritise increasing attendance and ensure activities are developmentally appropriate and engaging. The insights from this pilot study provide a foundation for refining school-based exercise interventions to improve strength and postural stability, with the goal of fostering intrinsic motivation and improving physical well-being. Intervention development to meet the needs of children with OWB may best be done with a holistic approach that involves children with OWB in the process. Co-production of interventions with target populations may provide the necessary insights to improve intervention design accordingly.

5 A Co-production approach to the development of a school-based exercise intervention.

5.1 Abstract

This study aimed to refine the school-based exercise intervention to improve postural stability and muscular strength in children with overweight and obesity from Chapter 4. A co-production approach to incorporate elements supporting feelings of autonomy, competency, novelty, and play creates an evidence-based, engaging, and child-centred program. Twelve children 7 to 11 years old with low activity levels participated in 5 1-hour workshops focused on the delivery and content of an exercise intervention focused on the tenets of self-determination theory (autonomy, competence, and relatedness). Workshops were audio-recorded, transcribed, and analysed iteratively, with each session informing the development of subsequent workshops. Reflexive thematic analysis, guided by self determination theory and the researcher’s experience, was used to identify, code, and refine themes, linking theoretical insights with observed behaviours during exercise sessions. Key refinements included self-determined challenges, novel exercises and play activities, smaller group sizes, and tailored modifications aimed at fostering intrinsic motivation and creating a supportive, participant-centred environment.

5.2 Introduction

Health interventions aimed at increasing postural stability and muscular strength are typically based on exercise science and require participants to repetitively perform the same exercises with progressive intensity or effort (Haff et al., 2016). Exercise interventions based on academic theories lack contextual understanding and are challenging to implement in school settings (Jago et al., 2023). The pilot study conducted in Chapter 4 showed that interventions based on sound scientific principles of challenging the neuromuscular systems consistently over eight weeks, resulted in less than optimal attendance and few beneficial changes to outcome measures. The focus groups conducted with participants (Section 4.3.6 and 4.4.2) highlighted key areas for intervention development, such as providing participants with autonomy, feelings of competency, and more elements of novelty and play.

Autonomy and competency are two key basic psychological needs (BPN) that need to be satisfied so that participants can enjoy and feel motivated to participate in PA (PA; Leptokaridou et al., 2015). Exercise interventions that prescribe strict exercise selection, involving the completion of specific sets and repetitions, can foster a controlling environment which thwarts BPN satisfaction. Moreover, a controlling environment may give children with overweight and obesity (OWB) a negative experience associated with exercise, and this may limit residual benefits to PA post-intervention. Whilst also impacting future participation in exercise and PA (Brown et al., 2015; Thiel et al., 2020).

Co-production is an emerging methodology in sport, exercise, and health research, where researchers collaborate with stakeholders—such as patients or target populations—throughout the research process to create context-specific, impactful research (Smith et al., 2023). By incorporating co-production into intervention design, researchers can tailor interventions to be more relevant and engaging for children, potentially improving attendance, reducing dropout, and fostering better adherence (Ells et al., 2018; Lister et al., 2023; Reed et al., 2021). This approach values principles of equality, diversity, and mutual learning, ensuring that the voices of those directly impacted by the interventions are central to the process (O'Mara-Eves et al., 2022; Smith et al., 2023).

Several studies have demonstrated how co-production may be successfully applied in OWB and PA interventions. For example, Mackenzie et al. (2021) used two one-hour workshops with office employees to develop an intervention grounded in social cognitive theory aimed at reducing sedentary behaviour in the workday. Key contextual insights such as access to showers likely to discourage vigorous activity during the work day and different appropriate communication techniques to implement the intervention in different workplaces were generated from the workshops. Anselma et al. (2019) engaged 9- to 12-year-olds in regular workshops over two years to design a childhood obesity prevention program using intervention mapping, which generated actions such as allowing children more choice and co-organisation of sports activities, greater provision of active playtime, environments and teaching active games to best engage with this, and education series and quizzes for healthy nutritional habits. Similarly, Clifford et al. (2023) worked with school children, teachers, and school leaders in multiple phases to develop a school-based intervention focused on motor competence and mental health, which provided an understanding of children's likes and dislikes of PA and the reasons behind them, and the barriers teachers perceive in children PA such as child behaviour and children’s own perceptions of their physical abilities and motivation. However, it is worth noting Clifford et al. (2023) reported challenges in engaging teachers due to their heavy workloads. While co-production has shown promise in intervention design, it does come with challenges, such as the time, resource, and emotional demands on stakeholders (Williams et al., 2020). Despite the variety of co-production methods and frameworks applied (i.e. design thinking or social cognitive theory), each is benefited from an approach to tailoring to the specific research context (Anselma et al., 2019; Hall et al., 2020; Mackenzie et al., 2021).

The aim of this study is to further develop the school-based exercise intervention outlined in Chapter 4. Using a co-production approach, the study seeks to refine the intervention aimed at improving postural stability and muscular strength in children with OWB. The co-production process will address key findings from the pilot study focus groups (Section 4.5.3), specifically the need for autonomy, a sense of competency, novelty, and play. By incorporating these elements, the intervention will remain evidence-based while ensuring it is suitable and engaging for children with OWB.

5.3 Methods

5.3.1 Participants

The developed intervention is aimed at children with OWB, and therefore, the participants in the co-production study should be representative of this population. However, singling out a group of only children with OWB within the school setting presented ethical concerns. In Chapter 4, both OWB and TW children took part in group exercises. However, the inclusion of active children who may have a different relationship with PA would potentially alter group discussion on how to develop the intervention in children with OWB. Therefore, only children with reported low levels of PA were recruited. Participants completed a PA questionnaire for children (PAQ-C) a threshold of <2.7 was as a score below 2.7 indicates PA below the recommended 60 minutes of moderate to vigorous physical activity (MVPA) and an increased risk for metabolic syndrome (Benítez-Porres et al., 2016; Voss et al., 2013). Twelve children, male and female between the ages of 7 to 11 (9.00 ± 0.42 years), were recruited with a mean score PAQ-C score of 2.14 ± 0.47. This reflects a similar number of participants in previous co-production processes (Anselma et al.,2019), allowing for absences and attrition whilst remaining a manageable number for group discussions and data analysis. Parental or guardian consent was obtained for each participant (Appendix H). Ethical approval was provided by St Mary's University Ethics Committee (Appendix G).

5.3.2 Co-production workshops

Participants took part in workshops once a week for five weeks at the participant's primary school, during the school day. Workshops lasted for up to 1 hour. Each week covered a different subject area (Table 5-1). The researcher-participant discussions were set around the tenets of self-determination theory (SDT; autonomy, competence, and relatedness). Workshops included the hands-on experience of the intervention using adapted formats and exercises and workshop-specific activities.

Each workshop session consisted of a brief introduction and main period of exercise session experimentation, and in some sessions (Table 1-5) workshop-type activities were included such as such as word clouds, group discussions and individual or group post-it note responses to prompts. Each session was recorded from the start to finish to capture all discussions, questions and answers throughout the workshops. Each workshop's exercise session experimentation component provided in-the-moment live feedback and adaptation, allowing for a precise (e.g. with reference to specific exercises, components or equipment) and deeper understanding of children's experiences of all components and responses to adaptations in real-time. Approaching adaptation in this manner allowed for clarification of participants' points of view and ensured that methods to address this feedback were done so fittingly. Further exploration of workshop sessions to derive a deeper understanding of participants' experience and motivation quality within the SDT framework were performed through reflexive thematic analysis (Section 5.3.3).

Table 5-1 Co-production workshop subject focus by week

Week	Workshop focus	Session Components	Discussion points
1	Introduction and education on the intervention practical experience of intervention and feedback on example exercises and delivery.	• Introduction to study, setting the scene and aims. • Pilot intervention delivery exercises.	Live feedback on exercises and delivery.
2	OMNI RPE - Challengingness and play – how can exercises be made easier or harder and more fun	• Introduction on challenge. • Exercise intervention session with adaptions noted from previous workshop session. Log books and exercise RPE. Additional, free play with equipment towards the end.	Live discussion and feedback on level of effort, challenge, feelings around these, how to adapt challenge of exerises
3	How to provide choice.	• Introduction and workshop activity about activites they like to do, would choose to do and why. • Exercise session delivery format with less control, more freedom over activity/exercises.	Discussion around chosen activities and why, adaptations to keep focus on intervention aim and live feedback on activities and exercises.
4	Format of delivery logbooks and how to record progress	• Introduction and workshop activity designing preferences for intervention components. • Exercise session further adaptations, freedom over exercise and play type components.	Discussion around delivert formats and logbooks, live feedback on more playful type activities and game.
5	Game examples and further exercise option testing	• Introduction, experimentation with accelerometers, experimenatatioon with equipment, exercise and games.	Discussion on feeling experience and enjoyment of different options.

5.3.3 Data analysis

Workshops were audio-recorded and transcribed after each week. Data collection and analysis were iterative, and each previous session informed intervention development and topics in subsequent workshops. A reflexive thematic analysis approach was taken to analyse data as it is a systematic but flexible method that can be applied to various research contexts, which made it suitable for the varied nature of the workshop-style data collection. Thematic analysis meant analysis could be informed by the tenants and existing research on SDT theory in children and exercise through a deductive theme development (Braun & Clarke, 2006, 2009, 2022). Additionally, the reflexive nature takes into consideration the role of the researcher, which is an important consideration as the researcher is the same person who delivered the pilot and will be delivering future exercise interventions. Familiarisation of the data was completed through transcribing, reading and relisting to audio recordings.

The coding and development of themes were performed with deductive orientation driven by SDT theory and researchers' knowledge and experience of the pilot intervention e.g. the main tenets of SDT formed initial subthemes, but greater meaning was derived by further analysis linking together this theory and children's behaviour experienced by the research during exercise sessions. The coding process identified potentially interesting and meaningful data (by highlighting and extracting data of relevant substance), applying theoretical context and meaning (e.g. grouping data into tenants of SDT), and then codes and labels were refined, data reread and the coding process repeated (with further contextual interpretation from the researcher's experience). Initial themes were generated, mapped and interpreted. Further review of data refined the themes and thematic map of the data. To limit the individual bias of a single researcher, a consensus on theme development and thematic map was made through discussion through each process step with JS (Braun & Clarke, 2022). Furthermore, to ensure rigour in the thematic analysis process, the 15-point checklist criteria for good thematic analysis were considered and adhered to (Braun & Clarke, 2006).

5.4 Results

The thematic analysis of co-production sessions identified three main themes. The first theme focuses on the effectiveness of exercises for appropriate adaptation, reporting exercise effort, exercise difficulty, and the role of competency within the exercise sessions. The second theme highlights ways in which the quality of motivation to attend and engage with sessions may be improved by a simple adaptation of 'participants' understanding, increasing novelty and moving towards a natural play-type environment. Theme 3 centred around the format and delivery of sessions to improve feelings of autonomy and relatedness.

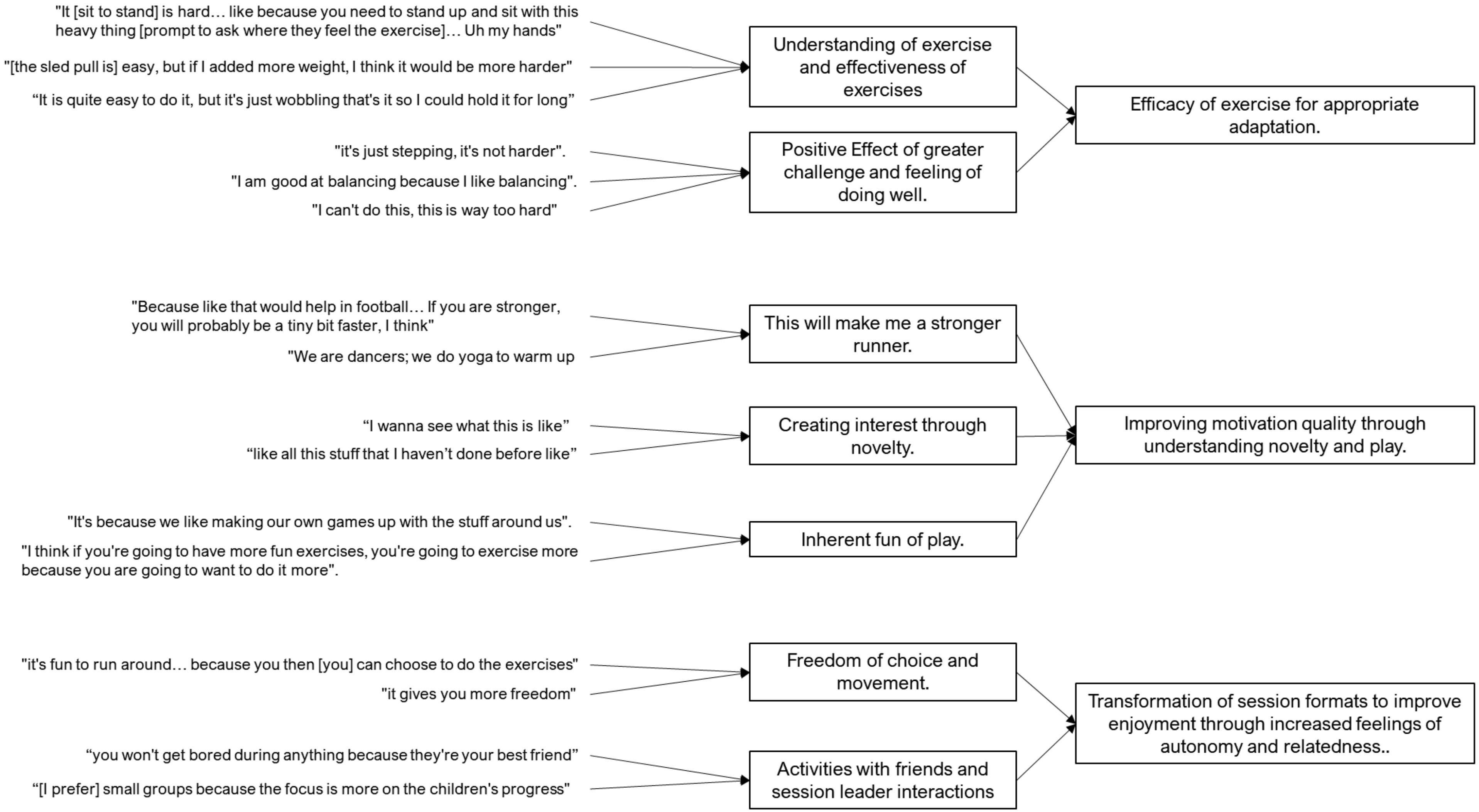

Figure 5-1 Thematic analysis codes and themes of co-production workshops.

Effectiveness of exercises for appropriate adaptation.

Within the theme of the effectiveness of exercises for appropriate adaptation, two subthemes were identified. The first centres around participants' understanding of exercise mechanisms, experience with exercises and descriptors of effort relating to individual exercises. The second subtheme explores the effort of the participants and focuses on the need for greater difficulty, optimal challenge and the role of this in feelings of competency.

Understanding of exercise and effectiveness of exercises.

This subtheme focuses on 'participants' understanding of exercise intentions and the suitability of exercises to the population to be effective for adaptation and reporting. For any given activity or exercise underpinned by theoretical knowledge, there will be an expectant focus on working particular muscles. Children were able to identify and describe areas of the body where exercises were affecting their body. This is useful for discerning the effectiveness of individual exercises and activities through the development period, as well as determining the effectiveness of a given resistance for an individual participant. One participant mentioned: "Yeh, ‘cos it's harder to kind of lift it with the legs [with weights]" (P9). Another participant explained: "I'd say it is in the middle [level of difficulty] because when you come back up, you have to push up with your leg" (P6). However, at times these clear descriptions of exercises working desired muscle groups were not present, meaning that there was either a lack of understanding or the movement was not creating the desired stimulus.

When prompted to describe their physical feelings of the exercises, participants reported more on the interaction with equipment. When asked about the sit-to-stand, participant 10 highlighted, "It [sit to stand] is hard… like because you need to stand up and sit with this heavy thing [prompt to ask where they feel the exercise]… Uh my hands". These types of misperceptions of effort focus persisted as exercises were adapted. For example, when participants tried the sit-to-stand (STS) exercise with the resistance held on the shoulders rather than the hands it was reported the exercise was "Very hard... [prompt to ask where]… in my shoulders.. [prompt to ask about feeling it in their legs] … not really… but with my feet, yes" (P4). This has implications for the reporting of perceived effort, particularly if it is used as a way to determine when to progress the intensity of exercises. Additionally, at times, participants also noted little to no effort or typical feelings of muscular work in the legs. This has implications for the overall effectiveness of these exercises in increasing muscular strength and improving balance. Bodily systems need to be appropriately stressed to bring about adaptation. If children feel no additional effort to complete these exercises, then they may be too easy or are not being performed correctly. However, there may be an element of miss reporting and participants not wanting to say something is hard or that they cannot do it.

Additionally, when considering the correct way to perform activities or exercises, participants focused more on an end goal of "completion" rather than the form of an exercise i.e. participants saw the completion of a monster walks exercise as getting from a to b with disregard for lower limb position or appropriate muscle activation. The discrepancy between what participants understand as successfully completing an activity and how an activity should be performed for it to be effective has implications for overall effectiveness. When asked how they would rate balancing on the Bosu ball out of 10, participant 1 said, " it is quite easy to do it, but it's just wobbling that's it so I could hold it for long". In this example participant 1 did not see that wobbling whilst balancing on a Bosu ball was a reflection of balance performance rather than focusing solely on the duration on the Bosu ball. Different verbal cues or visual cues may make exercises more effective for children, particularly those who are less active and likely to have less physical literacy.

It was natural for participants to describe effort and difficulty on a number scale. Before the OMNI RPE scale was introduced, when asked how they found the step-up exercise, participant 9 responded, "On a scale of 5, 5 being the highest, 3". Descriptions of effort often aligned with the RPE scale, and participants were able to describe the physical feelings of working at greater effort levels using phrases such as "strained" (P11), and "feel like jelly" (P7). Where children were unable to describe how they were feeling they would liken their feelings to phrases that made 'sense' to them. This is of particular importance because it provides language that can be used with children when trying to describe desired levels of effort. However, this was not true of all participants at all times; for example, one participant described a sit-to-stand exercise as "a little hard" (P10) on their legs but gave the exercise a 10 for the level of effort required to complete it. This discrepancy suggests the understanding of the RPE scale was not inherent, and a detailed and consistent description may be required. Participants were also able to identify ways in which exercises could be adapted to increase the effort required to complete them; one participant stated, "[the sled pull is] easy, but if I added more weight, I think it would be more harder". The need for exercises to be harder was a consistent theme throughout sessions.

The positive effect of greater challenge and feelings of doing well.

This second subtheme surrounds the reported positive feelings such as enjoyment and achievement from more challenging exercises, reports of competency linked with enjoyment and how these may impact the reporting of perceived effort. The original level of exercise difficulty was set too low. This was demonstrated when the researcher asked why a step exercise was not fun; Participant 2 responded, "it's just stepping, it's not harder". Exercises that were perceived as easy and requiring little effort were deemed boring as they lacked any challenge for children. When discussing the omni RPE scale, children associated the lower extreme end with being "boring" (P10), whereas for exercises that were perceived as more challenging, participants were "…determined to do it" (P9). When exercise load was increased through greater resistance, less stability, or additional task constraints, the exercises were more challenging and, therefore, more exciting for children to take part in as they required greater effort to complete.

Participants were able to challenge themselves and describe typical sensations associated with muscle exertion, such as tiredness or aching. While these descriptions help build a vocabulary to cue children during strength-based exercises, they may have limitations for balance-based activities, where the physical sensations of challenge differ from the muscular ache and fatigue experienced during strength training. However, there was a limit to the extent children would choose to challenge themselves. When asked if a participant completed 30 repetitions of an exercise as prescribed, they responded "no… because it started getting harder after a little bit" (P1). Additionally, when discussing why participants might not want to complete several repetitions of an exercise, participant 10 stated, "sometimes it might be because when you keep doing it, your legs just get tired of it, and you just want to move on". Challenge on its own was not inherently enjoyable, and exercises needed to be perceived as having elements of fun as well as adequately challenging children for increased and continued engagement. Enjoyable elements of the challenge came from the difficulty of the initial exercise and not from increasing the exercise intensity through increased repetitions or sets. This had implications for a programme initially based upon participants completing a programme of increasing intensity through increased volume as well as load. However, when the challengingness of an activity or exercise was deemed as too hard, this discouraged participants and thwarted feelings of competence.

In some instances, there was a discrepancy between the stated desire to challenge oneself and actual behaviour. When asked by a researcher what they enjoyed about a session, participant 1 responded, "I just love how I challenge myself… [when prompted to describe, relative to the RPE scale, how much effort they had to exert today (“7+”)]…no, zero". This may be due to participants parroting what others had said, telling the researcher what they thought was the right thing to say or an additional component of how and when children chose to make activities more challenging. However, there may have been some reluctance to report an activity or exercise as being hard.

During workshop activities, participants were asked to complete the phrase 'During sessions, I am good at…" participants were able to identify exercises or activities they felt they did well, with one participant answering, "I am good at balancing because I like balancing". Perceived competency of a given task was related to the enjoyment of that task, and children were able to identify activities that they felt they were good at regardless of actual competency level. Children expressed the need to feel and develop competency over time and to have this development recognised. The preference on how that was recognised seemed individual to children, with some reporting they would like to record progress "so I know if I improve my balance" (P9) and others preferring "to get on and try hard"(P3).

When prompted to state things they would like to get better at, children were able to identify session-based activities such as hoop hop, the sled pull, and balancing, whilst other children stated things like gymnastics and running faster. This is suggestive that children are able to identify exercises or activities that they would like to gain competency in. However, when children saw a gap in their competency level that is much different from their peers or session leader, it was exclaimed, "I can't do this, this is way too hard" (P3); this thwarted positive feelings of competency and, therefore, may potentially limit enjoyment and engagement in said activities.

Increasing motivation quality through understanding, novelty and play.

For the second theme, it was found that the co-production sessions highlighted ways in which adjustments to intervention exercise activities may directly impact motivation quality through three subthemes; This will make me a stronger runner (which focuses on understanding intervention benefits), increasing novelty, and the benefits of play activities.

This will make me a stronger runner.

This sub-theme focuses on the personal importance some participants had in beneficial intervention outcomes, therefore increasing the quality of motivation in sessions. The intervention aims to improve stability and increase lower limb strength. Recognising the benefits of the intervention suggests they may derive some personal importance from participating in the intervention and how it would be beneficial for them. One participant mentioned, "Because like that would help in football… If you are stronger, you will probably be a tiny bit faster, I think" (P2). Moreover, children were able to identify components of the exercise intervention that they would like to get better at, suggesting they place some value on those tasks or get some satisfaction from completing them. One child mentioned, "This will also make me a stronger runner" (P7). Additionally, some identify themselves with their physical activities; one child recalled, "We are dancers; we do yoga to warm up" (P5). Using dancers as an example, if children are aware that strength and balance will help them improve as dancers or that dancers also work on strength and balance, this may encourage a motivation type that is more driven by internal factors of importance and identity than external reward or repercussion.

Children were able to identify some of the basic mechanisms through which different exercises may achieve improvements in balance and strength. Two children were able to identify this: "you do it [get stronger] with weights" (P2 & P3). However, this understanding of mechanisms was not consistent; often, incorrect associations between exercises and adaptations were made ”… if you exercise too much your bones are going to get too loose”(P8). Moreover, focus often shifted from strength and balance in the lower limbs to strength of the upper body or away from strength and balance altogether . In a discussion around why a pair of participants had chosen a game of catch P1 responded “because it gives your arms strength and practice how far you can through and catch”. This misplaced focus has implications for effectiveness in unguided free play. Participants need to be guided in maintaining the focus on the intervention’s aims. Bridging the gap between the exercise and activities with how these bring about adaptations and resultant benefits may further improve motivation to engage with the prescribed exercises and activities if they see the value in the benefits, even if there is no intrinsic enjoyment of participating. However, there were two components that did increase motivation quality through innate enjoyment: novelty and play.

Creating interest through novelty

This subtheme centres around the appeal of new and novel activities and equipment and how this brings about engagement through innate curiosity and enjoyment. When asked what they found fun about an activity session P5 responded, "like all this stuff that I haven't done before". New activities have an inherent fun quality merely because they are new and different from children's normal types of PA. Novelty in equipment and exercises increases the engagement of participants through innate curiosity. Children expressed the desire for activities and equipment to "change…every week [but] repeat somethings …because like they might find the balancing bit fun" (P2), suggesting that continued novelty throughout an exercise programme is needed and not just for the programme to be new at the beginning. Continually repeating exercises and activities throughout the course of an intervention every week would fail to continuously engage and excite children, except if it was a particular activity or piece of equipment from which they derived inherent satisfaction. In addition to the natural draw of novel exercises, activities with elements of play and games were particularly appealing.

Inherent fun of play

This subtheme highlighted children's inherent enjoyment of play and presented a more natural way for children to engage in PA. During free play activities (a time when activities were not structured but the equipment was available to participants), children naturally created new games and played games they already knew (e.g., catch, football). When questioned why time in free play was more appealing, participant one responded, "It's because we like making our own games up with the stuff around us". Games are likely inherently more enjoyable and feel less like exercise or work. Playing in this way may feel more like a natural way for children to engage in exercise. When discussing set games P9 stated, "I think if you're going to have more fun exercises, you're going to exercise more because you are going to want to do it more". Set games also had increased engagement, and children expressed enjoyment of these types of activities despite the more controlling nature of being told to complete or play particular games. Play, whether guided or self-led, increased the reported enjoyment of sessions.

Transformation of session formats to improve enjoyment through increased feelings of autonomy and relatedness.

The third theme developed focus on session formats and how this could be modified to better support a more autonomous type of environment and increase enjoyment. The first subtheme builds on the natural play type environment and surrounds the need for a less controlling environment and greater freedom within the physical space. The second subtheme focuses on the role of peers and session leaders to facilitate enjoyment as well as feelings of competency to support engagement with the intervention.

Freedom of choice and movement

This subtheme explored children's desire to have freedom of choice over their activities. When exploring why children preferred free play activities, they stated, "it's fun to run around… because then [you] can choose to do the exercises" (P7), "it gives you more freedom" (P6). Rigid prescription of exercises is a very controlling environment, and the chance to be free in the environment, with exercises and equipment, was preferable and more enjoyable for children. When experimenting with different ways to record progress, P3 shared, "I don't want to record, [prompted for reasoning by the researcher], because before you could just like do the activities, but if you are recording, it might make you slow down". The detailed recording of exercises during a session felt burdensome to children and detracted from the enjoyment of being active. Moreover, in the adaptation of exercise and free play, children would exhibit a preference for less rigid and stationary types of activities that allow freedom of movement in space. For example, running around may feel more freeing and enjoyable than static grounded exercises. It is also important for children to have the option to do set exercises should they wish rather than have them only prescribed.

Activities with friends and session leader interactions.

This last subtheme focuses on the effect of other people within sessions on participants' motivation quality, how friends create a more fun environment and the role of the session leader in providing feedback and supporting feelings of competency. Children expressed a preference to do activity sessions with friends. P7 outlined:

> “Because you love your friend and no matter what you do with them you never really get bored you and a friend is, therefore, someone you can look up to, and you won't get bored during anything because they're your best friend .“

Being able to work with friends reduced the monotony of exercises or feelings of effort as they naturally boosted one another and played together. Being with peers (children of the same age or from the same class within the school) created an environment in which they were already familiar and comfortable to talk and play, which generated greater opportunities to explore and be creative.

The relationship between teacher/coach and children was also an important factor for children during exercise sessions. Children stated a preference for "small groups because the focus is more on the children's progress" (P1). A low child-to-session leader ratio would provide participants with more time and focus from the session leader to provide them with support and encouragement. Moreover, children (tending to be more from the girls within the group) expressed the need for greater reassurance from the session leader, suggesting feelings of competency or confirmation of competency were somewhat dependent on assurance from the person leading sessions. This was not restricted just to verbal feedback but also required those leading sessions to be actively involved with children and activities beyond just demonstrating activities.

5.5 Discussion

The co-production group of 12 children with habitual low activity levels taken through five workshops were able to experience the pilot exercise intervention (Chapter 4), explore intervention exercises and delivery formats, provide feedback on their experiences and develop the exercise intervention. The key components of intervention delivery as a result of these workshops are discussed below and summarised in Table 5-2.

Table 5-2 Summary of the derived intervention adaptation components.

Piloted intervention	Key findings in Pilot intervention focus group feedback	Points for Intervention Adaptation
A brief introduction to the intervention	• Some exercises may be painful or inappropriate. • Session should not be conducted during play times. • More challenge is needed. • More choice is needed. • More variation, novelty, and play are needed. • Alternate way to asses adherence is needed. • Not clear if participants understood or valued the role of exercise intervention.	Consistent expression of aims and valued benefits.
Prescribed repetitions and sets		Focus on challenges and feelings of physical effort rather than prescribed workloads.
Session log books		Take session RPE and use accelerometers to reduce miss reporting and burden to participants.
Delivered to a whole class		Smaller groups to foster greater feelings of classmate and teacher relatedness.
Circuit style delivery		Freedom to explore and play with some guidance.
<u>Exercise selection:</u>		<u>Exercise selection:</u>
• *Sit to Stand with added weight* • *Monster walks* • *Hip thrust* • *Nordic hamstring exercises* • *Hops* • *Step up* • *Plank* • *Bodyweight glute bridge*		Adaptation and variation to exercises e.g. addition of sled pull and wall squat exercises along with sit-to-stand exercises to target hip and knee extension strength.

5.5.1 Focus on challenge and physical feeling of effort.

In the original intervention, exercises were prescribed with specific sets and repetitions, overlooking individual differences in motivation and perceived effort. This rigid structure may have hindered intrinsic motivation, leading to disengagement, boredom, or frustration, particularly among children with OWB who are less active or competent. McWhorter et al. (2003) discussed the need for children to have self-set realistic goals for self-improvement in order to promote motivation in children with OWB to exercise. Therefore, a shift towards participant-set challenge levels based on perceived effort was proposed to foster autonomy and, therefore, intrinsic motivation within the exercise sessions. Participants in this co-production study were able to set their own level of difficulty, which made them feel competent but adequately challenged and, therefore, engaged with activity sessions. The move away from prescribed sets and repetitions allows for each participant to achieve their own attainable successes within sessions, which will further their own perceived competence and, therefore, drive further improvements in actual motor competence (Morano et al., 2014). By allowing children to set their own challenges based on their perceived effort levels, the intervention seeks to promote a sense of ownership and empowerment over their PA experience, aligning with the principles of SDT (Lewis et al., 2014).

5.5.2 Session RPE and accelerometers

Individual exercise logbooks, wherein children were previously required to note their RPE for each exercise, were eliminated. Instead, a session-level RPE was introduced alongside the integration of accelerometers to monitor overall activity levels. This departure from exercise-specific RPE tracking was motivated by the transition towards a more flexible and child-driven approach, wherein prescribed sets and repetitions were replaced with children setting their own activities and challenge levels. In this context, the use of RPE for individual exercises as a tool to increase workload is redundant. Whilst, session RPE compared to individual exercise RPE is highly correlated in children with OWB (r = 0.88), it should be noted that values are higher in comparison to individual exercise averages for the same session (McGuigan et al., 2008). The discrepancy between the two methods of collecting RPE data suggests that session RPE may be impacted by accumulative fatigue or other components such as warm-up and cool-down (McGuigan et al., 2008). However, the use of visual scale and numbering perceived effort was demonstrated as a useful tool in workshops in the current study to promote and describe the desired level of effort for activities. Faigenbaum et al. (2004) reported that children's RPE of 6 to 7 corresponded approximately with desirable training loads of 75% 1RM, and therefore, this level of RPE should be used when describing the desired effort level participants should be striving to achieve during activities.

The use of accelerometer tracking is a passive and objective means to quantify total activity and activity intensity that will replace participant-reported completed set and reps in logbooks. This change lessens participant burden and addresses issues with false reporting described in the pilot study (Chapter 4). Objective data of total activity and intensity may also be used as a control comparison across different groups taking part in the intervention. Whilst a less structured programme allows for the context of individuals to be addressed and improves components of autonomy and enjoyment, the internal validity of the intervention is affected (Jago et al., 2023). By shifting the focus to session-level RPE and accelerometry-based activity tracking, the intervention aimed to streamline data collection while providing a comprehensive assessment of overall PA engagement. This adjustment not only simplifies the monitoring process but also aligns with the overarching goal of promoting autonomy and self-regulation among participants, as advocated by SDT.

5.5.3 Adaptation and Variation in Exercises

Another pivotal adaptation to the intervention involved increasing the variation of activities and exercises offered to the participants within sessions and over the course of the intervention period in order to increase novelty. Previously, the intervention relied on a relatively static set of exercises repeated weekly, potentially leading to monotony and reduced engagement over time. There is growing support for novelty as one of the key components of intrinsic motivation (Fierro-Suero et al., 2020). The lack of novelty within a physical education (PE) class has similar effects on motivation quality as thwarting feelings of autonomy, competence and relatedness (González-Cutre et al., 2016). The intervention has been restructured to incorporate a broader range of activities, ensuring variety and excitement in recognition of the importance of novelty in sustaining engagement and motivation.

In addition to increasing novelty, the adaptation of exercises to better target desired outcomes emerged as a necessary aspect of the intervention refinement. Workshops in the current study identified that some exercises may not effectively engage the intended muscle groups or desired aspects of stability. Modifications were implemented to optimise effectiveness and ensure alignment with intervention objectives. This process involved simplifying or refining exercises and providing specific verbal cues to enhance participants' understanding and execution. The greater ability to understand instructions and remember cues is positively associated with motor skill ability; given the lower habitual activity levels of children with OWB, it is, therefore, likely they have had less practice and exposure to motor skills and associated cues (Hastie et al., 2018). By tailoring exercises to elicit desired responses and employing appropriate cues, the intervention aimed to maximise the benefits of each activity.

5.5.4 Freedom to explore, exercise and play

An important modification to the intervention delivery format was the transition from a circuit-style delivery of exercise sessions to a more freeform approach that encouraged children to explore exercises, equipment, and play naturally. In the circuit-style format, children may have felt constrained by predetermined exercise stations and routines, limiting their opportunities for self-expression and exploration. By allowing children greater freedom and flexibility in their PA choices, the intervention aimed to foster a sense of ownership and personal agency over their exercise experience. Conversely, the freeform style provided a more dynamic and interactive environment where children could experiment with different activities and equipment based on their interests and preferences. This allows for the context of each individual to be addressed, which is a crucial factor in child PA intervention programmes (Jago et al., 2023). This approach not only empowered participants to take an active role in shaping their exercise experience but also encouraged creativity and spontaneity, moving towards a more active play style, enhancing enjoyment and possible learning (Alexander et al., 2014a). Moreover, by embracing a more open-ended and child-centred approach, the intervention sought to cultivate a positive exercise environment that nurtured intrinsic motivation and long-term adherence to PA behaviours (Alexander et al., 2014b). However, it should be noted that guidance is required to maintain exercise and intervention aims. This may be maintained by the equipment available and suggested activities during any given session that are appropriate for intervention aims but allow for flexibility for children to explore those and create new activities from them, with guidance on task constraints to maintain the purpose of activities.

The transition to a freeform style of delivery also underscored the importance of fostering relatedness and social interaction within the exercise sessions, key components of SDT. Furthermore, the freeform style allowed for greater interaction between participants and session leaders, facilitating meaningful connections and positive rapport. Overall, the transition to a more freeform style of delivery facilitates an autonomy-supportive environment and relatedness within the exercise sessions but also provides a supportive and empowering environment that may promote positive exercise experiences and long-term motivation among participants.

5.5.5 Small groups

The adjustment from large class groups to small groups represented a fundamental change aimed at enhancing engagement and motivation within the exercise intervention. This modification was informed by the findings of the thematic analysis, which underscored the importance of peer interaction and individualised attention in fostering enjoyment and competence among participants. In large class settings, children may have felt less connected to their peers and session leaders, leading to feelings of anonymity and reduced engagement. Conversely, small group settings provided a more intimate and personalised experience, allowing for greater interaction and social connection among participants and facilitators. Within a PE context, the perceived relatedness to peers and teachers is crucial to needs satisfaction (Vasconcellos et al., 2020). Additionally, the smaller group size facilitated more targeted feedback and guidance from session leaders, enabling participants to receive tailored support and encouragement based on their individual needs and abilities. Whilst it is important to address these needs in the current co-production method and adapt the intervention accordingly, this may have implications for the scalability of the intervention beyond the current research context.

5.5.6 Consistent expression of aims and valued benefits

The transition towards consistent expression of the aims of the intervention was driven by the recognition of aligning intervention outcomes with children's understanding and self-beliefs to derive value from the program. Children in the current study stated some value in the intervention outcomes as they align with personal identifiers (i.e. being dancers or playing football). Identified regulators of motivation, such as these, along with intrinsic motivation, are important to an autonomous environment and improved motivation quality (Teixeira et al., 2012). Children expressed varying levels of understanding regarding exercise intentions and the effectiveness of specific activities. A greater and more consistent messaging of the activity, adaptation and physical outcome benefit pathway may increase understanding and motivation quality through identified regulation. Overall, the move towards consistent expression and aims of the intervention represents a strategic adaptation informed by the principles of SDT, aimed at enhancing motivation, engagement, and overall effectiveness of the program.

5.5.7 Limitations

This co-production study addresses many of the challenges of the piloted intervention. However, some limitations exist in the current approach. The inclusion of TW participants along with Participants with OWB in the current study was necessary so as not to stigmatise and single out groups of children with OWB within the school setting. Therefore, the adaptations made to the pilot intervention are not solely OWB-specific. However, the effect of non-OWB children's perspectives influencing intervention adaptation beyond what is effective for children with OWB was mitigated by the low habitual PA inclusion criteria. Children who habitually take part in low levels of PA may do so because of low motivation despite no impact on weight status. Secondly, the children and school in the current study who have shaped the current intervention through the co-production process will not be the same participants who take part in the main intervention. Therefore, the conclusions and resultant adaptations are assumed to be generalisable to a wider OWB child population.

5.5.8 Implications

This study presents a novel method combining live within-session intervention development of practical elements and analysis of workshop discussions within the SDT theory framework in children with OWB to develop a school-based exercise intervention which may be replicated in future work. Components such as novelty, challenge, choice and play are important to children's enjoyment in an exercise intervention. The findings of this study may be used when considering exercise intervention design in children, particularly how autonomy-supportive environments may be achieved in conjunction with intervention aims.

5.6 Conclusion

In conclusion, the adaptation of exercise interventions for children through a co-production approach framed within SDT principles demonstrates the potential to enhance motivation, engagement, and overall effectiveness. Through a comprehensive thematic analysis of workshops, key themes emerged, guiding refinements to the intervention design. These adaptations encompassed a shift from prescribed sets and repetitions to self-determined challenges based on perceived effort, the introduction of novel activities to sustain interest, and the transition from circuit-style delivery to a more freeform approach to foster autonomy and exploration. Additionally, adjustments aimed at optimising effectiveness and aligning with participants' understanding and beliefs were made, such as smaller group sizes, consistent expression of intervention aims, and tailored exercise modifications. The co-produced intervention aims to create a supportive environment that nurtures intrinsic motivation through competence, autonomy, relatedness, and novelty satisfaction among participants. Ultimately, by fostering a positive exercise environment that aligns with participants' needs and values, it is hoped that intervention attendance, engagement and effectiveness will be improved, and participating children will feel positively about sessions and promote PA.

6 Implementation of a co-produced school-based exercise intervention to improve physical function in overweight and obese 7-11 year olds.

6.1 Abstract

The aim of this study was to evaluate the effectiveness of a co-produced school-based intervention designed to improve postural stability, muscular strength, clinical measures of physical function, three-dimensional gait, and physical well-being in overweight and obese children aged 7-11 years. The study employed a 9-week co-produced exercise intervention held twice weekly at schools, incorporating dynamic warm-ups, lower limb strength and static and dynamic stability exercises with creative play. Pre-, post-intervention, and follow-up testing of physical well-being and physical function measures were conducted at St Mary's University. Nineteen overweight and obese children in the experimental group and thirteen overweight and obese children in the control group completed pre-, post-intervention, and follow-up testing. The intervention was successful in maintaining engagement, enjoyment and basic psychological needs satisfaction throughout. The experimental group maintained body mass and reduced body mass index Z-scores, while the control group showed increased body mass with no change in body mass index Z-scores. The intervention had a beneficial impact on lower limb strength. Additionally, the experimental group demonstrated increased hip flexion and adduction strength, improved performance in sit-to-stand and timed-up-and-go tests and reduced midfoot eversion post-intervention, with no changes observed in the controls. A school-based co-produced exercise intervention is beneficial for improving measures of physical function in overweight and obese children.

6.2 Introduction

As outlined in Section 1.1, childhood overweight and obesity (OWB) remains a global public health concern (World Health Organization, 2019). The prevalence of OWB among children has been steadily increasing over the last 40 years, both in the UK and globally, with a negative impact on health and well-being established (Chan & Chen, 2009; Omer, 2020; World Health Organization, 2016). Children with OWB face an elevated risk of developing obesity-related diseases, such as cardiovascular disease and metabolic syndrome in later life. Additionally, as outlined in Section 1.2, OWB negatively impacts physical well-being, including increased pain prevalence, reduced physical health related quality of life (HRQoL), and lower levels of physical activity (PA; Page et al., 2005; Riaz et al., 2010; Tsiros et al., 2012; Tsiros et al., 2014).

Physical function impairments in children with OWB are well-documented (Section 1.3), with deficits observed in tasks such as the six minute timed walk (6MWT), sit-to-stand (STS), timed-up-and-go (TUG), and single-leg stance (SLS) tests (Merde-Coskim et al., 2017; Nunez-Gaunard et al., 2013; Tsiros et al., 2012). These impairments are compounded by lower PA levels, creating a cycle of reduced physical function and further weight gain. This highlights the urgent need for targeted interventions to address these challenges in children with OWB. Cross-sectional studies suggest that the primary factors contributing to physical function deficits and gait deviations in children with OWB are greater body mass, relative muscle weakness, and poor postural stability (Singh et al., 2021; Abdelmoula et al., 2012; Garcia-Vicencio et al., 2016; Maffiuletti et al., 2008; Theis et al., 2019; Tsiros et al., 2013). Consequently, improving muscular strength and postural stability has been identified as a critical focus for exercise interventions aimed at breaking the negative cycle associated with childhood OWB (Faigenbaum et al., 2023; Schranz et al., 2013; Tsiros et al., 2016).

Excess body weight increases the metabolic cost of walking due to the greater workload placed on lower limb muscles, contributing to biomechanical inefficiencies and slower walking performance in children with OWB (Peyrot et al., 2009). Biomechanical differences in children with OWB compared to their TW peers have been observed at the hip, knee, and ankle during all phases of the gait cycle (Molina-Garcia et al., 2019). To enhance stability, children with OWB adopt compensatory strategies such as increasing their base of support, walking slower, and spending more time in the double support phase of gait (Gushue et al., 2005; Huang et al., 2013; Shultz et al., 2014). Greater body mass increases joint loading (Gushue et al., 2005; Lerner et al., 2016), and altered foot motion may create adverse plantar loading (Mahaffey et al., 2016; Stolzman et al., 2015). children with OWB exhibit greater frontal plane motion and altered sagittal plane hip and ankle movement patterns, likely due to reduced relative muscle strength in the lower limbs (McMillan et al., 2010; Orantes-Gonzalez & Heredia-Jimenez, 2021; Shultz et al., 2014). Additionally, OWB gait is characterised by a more everted and abducted foot position, indicative of flatter foot posture (Mahaffey et al., 2016). Such altered biomechanics place excessive and uneven loads on the immature musculoskeletal (MSK) system, increasing the risk of pain and maladaptive structural changes over time (Wearing et al., 2006).

As outlined in Section 1.4, evidence suggests that incorporating balance and resistance training can improve postural stability and muscular strength in children with OWB. However, traditional exercise interventions often fail to address children’s psychological needs, leading to low attendance and adherence and high drop-out rates. Chapter 4 piloted a school-based exercise intervention to evaluate the feasibility of conducting pre, post and follow-up testing over a six-month period in OWB 7-11 year-old participants. This pilot study identified key barriers to implementation, including low attendance and issues in self-reporting adherence, which could limit any of the intervention’s potential to improve physical function of children with OWB. These findings align with broader evidence that children with OWB face unique challenges, further emphasizing the necessity of an inclusive and participant-centred approach.

The co-production approach to intervention development in Chapter 5 engaged participants in collaboratively redesigning the intervention to ensure alignment with their needs, values, and preferences. Key adaptations were identified, including novelty to sustain interest, smaller group sizes, tailored exercise modifications, a reduction in controlling environment format, and more play to enhance motivation and engagement. The co-produced intervention was designed to foster intrinsic motivation by supporting competence, autonomy, relatedness, and novelty satisfaction, creating a supportive environment. The current study builds upon this foundation by implementing the Co-produced with children with OWB targeting Posture stability and muscular Strength (COPS) intervention and evaluating its impact on physical well-being and physical function in children with OWB aged 7-11 years. The aim of this study is to determine the effectiveness of a co-produced school-based intervention designed to improve postural stability and muscular strength, clinical measures of physical function, 3D gait and physical well-being in children with OWB.

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6.3 Methods

6.3.1 Participants

OWB children aged 7 to 11 years (male and female) were recruited from schools in the London borough of Hounslow. Teachers from each representative school contacted parents to invite their children to take part in the research. Inclusion required children to be classified as OWB by age and gender-specific body mass index (BMI) Z-score based on UK90 reference curves and Department of Health thresholds (Cole et al., 1995). Participants were excluded from analysis if they had any medical condition or injury affecting neuromuscular or orthopaedic integrity resulting in altered foot posture or gait disturbance. TW Children were included in activity sessions to reduce the risk of any stigmatisation, but their data were not collected. The school determined the timing of intervention settings (which 2 days of the week and the time of the day) that best fit with the school's availability. Parental or guardian consent was obtained for each participant (Appendix J). Ethical approval was provided by St Mary's University Ethics Committee (Appendix I).

6.3.2 Study design

Testing took place from the beginning of the spring term (January 2022, 2023, and 2024). Participants attended baseline testing over two weeks, after which the intervention programme began. The experimental group completed nine weeks of exercise intervention (1-week rest over the half term). Both intervention and control groups returned for post-intervention testing in the two-week period after the intervention was completed. Participants then returned for follow-up testing three months after the end of the intervention. All pre, post, and follow-up testing occurred at St Mary's University Twickenham, and interventions took place at host schools.

6.3.3 Intervention design

Intervention sessions were 1 hour long, held twice a week, and participants were provided with a hip-worn ActiGraph accelerometer (recording at 80 Hz) to wear for the duration. Each intervention session consisted of a dynamic warm-up game, a demonstration of the set exercises (Table 6-1), a reiteration of the effort levels to aim for (7 or above on the OMNI RPE scale; Robertson et al., 2005), and encouragement to play and challenge themselves. At least one exercise targeting every muscle group or stability was included in each session, and exercises were not repeated in consecutive sessions to maintain a sense of novelty. Participants were encouraged to be creative and play but were guided back to the intervention focus if needed (e.g., instead of simply playing catch, participants were encouraged to incorporate a balance task while playing). At the end of each intervention session, participants were shown the OMNI RPE scale (Robertson et al., 2005) and asked to rate the session. Accelerometers were returned at the end of every session, and the activity recording was stopped. Participants were instructed to remove their accelerometer if they were asked to sit out for a period due to poor behaviour (this time was not included in the intervention PA analysis). The control group continued with normal school activities.

Table 6-1 Summary of co-produced intervention exercise selection, progression strategy of each exercise, examples of play activities that occurred and the focus of muscular work or stability.

Exercise/Variations	Progression	Play Examples	HE	HF	KE	KF	AP	HABD	Stability
Sit to Stand	Increased external load Unilateral Stance Unstable surface	Most repetitions completed	●		●				○
Wall squat	Increased external load Unilateral Stance Unstable surface	Combined with static balance board exercises	●		●				○
Sled pull	Increase external load Increase velocity	Races from end to end	●		●		○		
Monster walks	Increased external load	Combined into race challenges or assault courses						●	
Lateral leg raise	Increased external load	Maximal repetition challenges with friends						●	
Lateral shuffle	Increased external load Unstable surfaces (i.e. on balance pods)	Combined into ball throwing game						●	○
Ball kicks	Increased external load	Making as much noise as possible				●			
Bum kicks	Increased external load					●			
Marching	Increase external load Increase velocity	Make-believe marching as group		●					
Step up	Increased external load on lead leg Increased external load on whole body	Included in child build assault courses	●	●	●				○
Sled push	Increase external load Increase velocity	"Pit Stop" style game increasing weight every meter	●	●	●	○	○		
Hops	More complex patterns and distance of hops	Tag but only moving via hopping hoop to hop					●		
Jumps	Increase obstacle height	Included in child-built assault courses	●		●	●	●		
Leaps	Increase distance	Included in child-built assault courses	●		●	●	●		
Skipping	Increased time with Increasing coordination	Group skipping					●		
Balance board exercises	Unilateral stance Increase in the difficulty of the board. Eye open and closed conditions.	Balance board joust with pool noodles							●
Dynamic Balance exercises (moving whilst balancing)	Narrower beams, Unstable surfaces (i.e. balance pods) Change of directions	Dodgeball style game whilst having to move around on beams						○	●

HE = Hip extension; HF = Hip flexion; KE =Knee Extension; KF = Knee Flexion; AP = Ankle plantarflexion; HABD = Hip abduction; ● = main focus of exercise, ○ = secondary focus through particular progression.

6.3.4 Data collection

Data collection methods for anthropometrics, assessment of pain, HRQoL, PA, six minute timed walk (6MTW), timed-up-and-go (TUG), sit-to-stand (STS), single leg stance (SLS), muscular strength, postural stability, and 3D gait analysis were carried out as described in general methods (Chapter 2). The Bodpod, previously used in the pilot study (Chapter 4) for body composition by air displacement plethysmography (ADP) assessment, was no longer operational due to equipment malfunction. Repair or replacement of the Bodpod imposed significant costs and time delays, making it impractical to continue its use. Additionally, the Bodpod's design presents challenges for paediatric populations; the confined environment can feel uncomfortable or intimidating for children, which previously led one participant to decline participation (Section 4.4). Therefore, bioelectrical impedance assessment (BIA) was selected as an alternative method for body composition estimation. BIA offers several advantages, including ease of use, cost-effectiveness, and portability, making it more suitable for clinical and research settings. Its non-invasive nature also reduces barriers to participation. Body composition assessment by BIA was completed as per the methods outlined in Section 2.1.2.

6.3.5 Statistical analysis

Statistical analyses of body composition, pain, physical HRQoL, PA, postural stability and muscular strength were conducted using SPSS software (version 30.0). The normality of the data was assessed using the Shapiro-Wilk test. Baseline differences between groups were evaluated with independent samples t-tests for parametric data. A 2×3 repeated measures ANOVA was performed to evaluate the effects of group, time, and group × time interactions, with *post hoc* tests conducted using Bonferroni corrections where applicable. Logarithmic transformations were applied to non-parametric variables. If transformation did not resolve normality, Friedman's test was employed to assess within-group differences over time, and the Kruskal-Wallis test was used to examine between-group differences at each time point. A significance level of $p < 0.05$ was applied throughout the analysis Bonferroni corrections to control for type I error were applied to post-hoc tests.

6.4 Results

A total of 84 children were recruited from six schools in the London Borough of Hounslow, and 41 of these children were excluded as TW. Over the course of the study period, seven children from the experimental group were excluded, and four from the control group (Figure 6-1). No participants chose to drop out from the experimental or control groups. The baseline characteristics of the included participants are in Table 6-2.

Table 6-2 Summary participant characteristics for the experimental and control group included for analysis.

	Gender	Age (years)	Height (m)	Weight (kg)	Weight status	FM%
Experimental *n* = 19	Male *n* = 11 Female *n* = 8	8.9 ± 1.2	1.44 ± 0.09	50.71 ± 14.71	Obese *n* = 13 Overweight *n* = 6	40.46 ± 6.45
Control *n* =13	Male n = 8 Female *n* = 5	9.5 ± 1.3	1.46 ± 0.08	51.35 ± 13.73	Obese *n* = 7 Overweight *n* = 6	39.74 ± 7.24

Note: FM = Fat mass

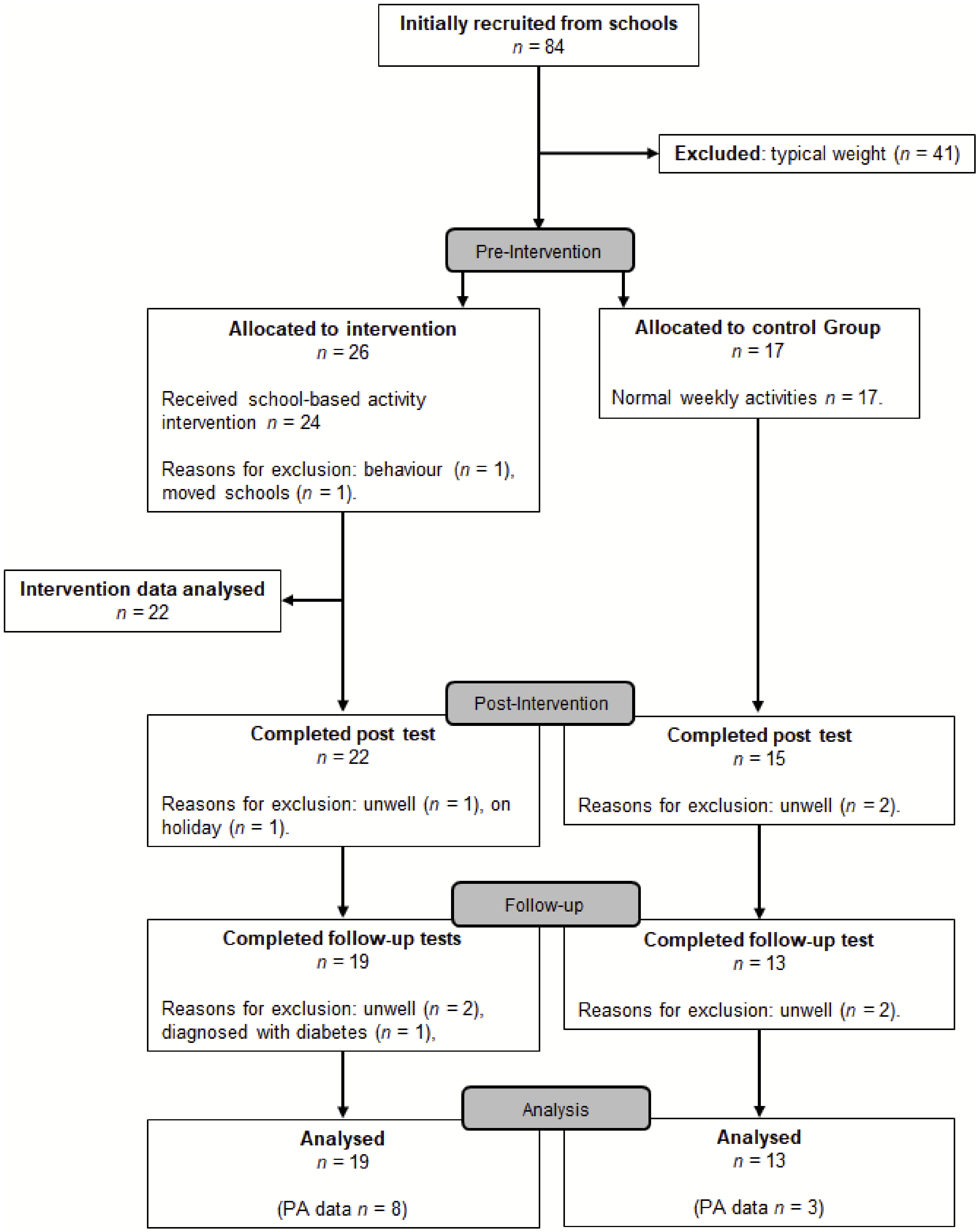

Figure 6-1 Summary of study recruitment, group allocation and excluded participant numbers.

Note: PA= Physical activity

6.4.1 Intervention attendance, intervention activity, basic psychological needs satisfaction and enjoyment.

Analysis of the intervention attendance and activity is based on 24 participants who completed the exercise intervention (Table 6-3). Mean intervention session attendance was 72.28% (range: 56.25 - 87.5%). Absence from sessions was due to school closures as a result of teacher strikes (35.64%), Covid or other illnesses (26.73%), the school not being able to accommodate sessions due to spaces being used for special assemblies or other activities (22.77%), and participants taking part in other school activities or trips (14.85%). On average, 52.4 ± 10.98 % of session time was spent in MVPA, and 23.1 ± 9.23% in sedentary activity. The mean RPE was 5.40 ± 3.33 (range: 0 - 9.58). A statistically significant difference in mean total activity counts between sessions ($F_{(15)} = 3.223$, $p < 0.001$) was found. *Post hoc* comparisons indicated session 14 to have significantly greater total activity counts than session 1 (p=0.002), 3 (p<0.001) and 5 (p=0.001). Mean counts per minute did not significantly differ across sessions ($F_{(15)} = 1.320$, $p = 0.191$; Figure 6-2). Sedentary time significantly differed across sessions ($F_{(15)} = 1.742$, $p = 0.044$), but *post hoc* tests revealed no individual differences in sedentary time between sessions. MVPA did not significantly differ across sessions ($F_{(15)} = 1.258$, $p = 0.230$).

Table 6-3 Participant characteristics for intervention attendance, intervention activity, basic psychological need satisfaction and enjoyment analysis

School	Gender	Age (years)	Height (m)	Body Mass (kg)	FM%	Attendance
A n= 5	Male n = 1 Female n= 4	7.6 ± 0.89	1.38 ± 0.08	41.8 ± 11.16	31.12 ± 7.16	72.5 ± 10.46
B n=4	Male n = 3 Female n= 1	8.25 ± 0.50	1.38 ± 0.07	41.48 ± 4.29	36.31 ± 3.18	81.25 ± 7.21
C n =11	Male n = 7 Female n=4	9.9 ± 0.99 *	1.5 ± 0.09	65.36 17.36	43.83 ± 3.12	70.0 ± 6.45
D n=4	Male n = 2 Female n = 2	10.75 ± 0.50 *	1.49 ± 0.02	51.92 ± 6.91	42.25 ± 2.06	67.75 ± 8.84
Total n=24	Male n = 13 Female n = 11	9.26 ± 1.42	1.46 ± 0.09	53.7 ± 16.68	4.57 ± 6.31	72.28 ± 8.59

Note: FM= Fat mass

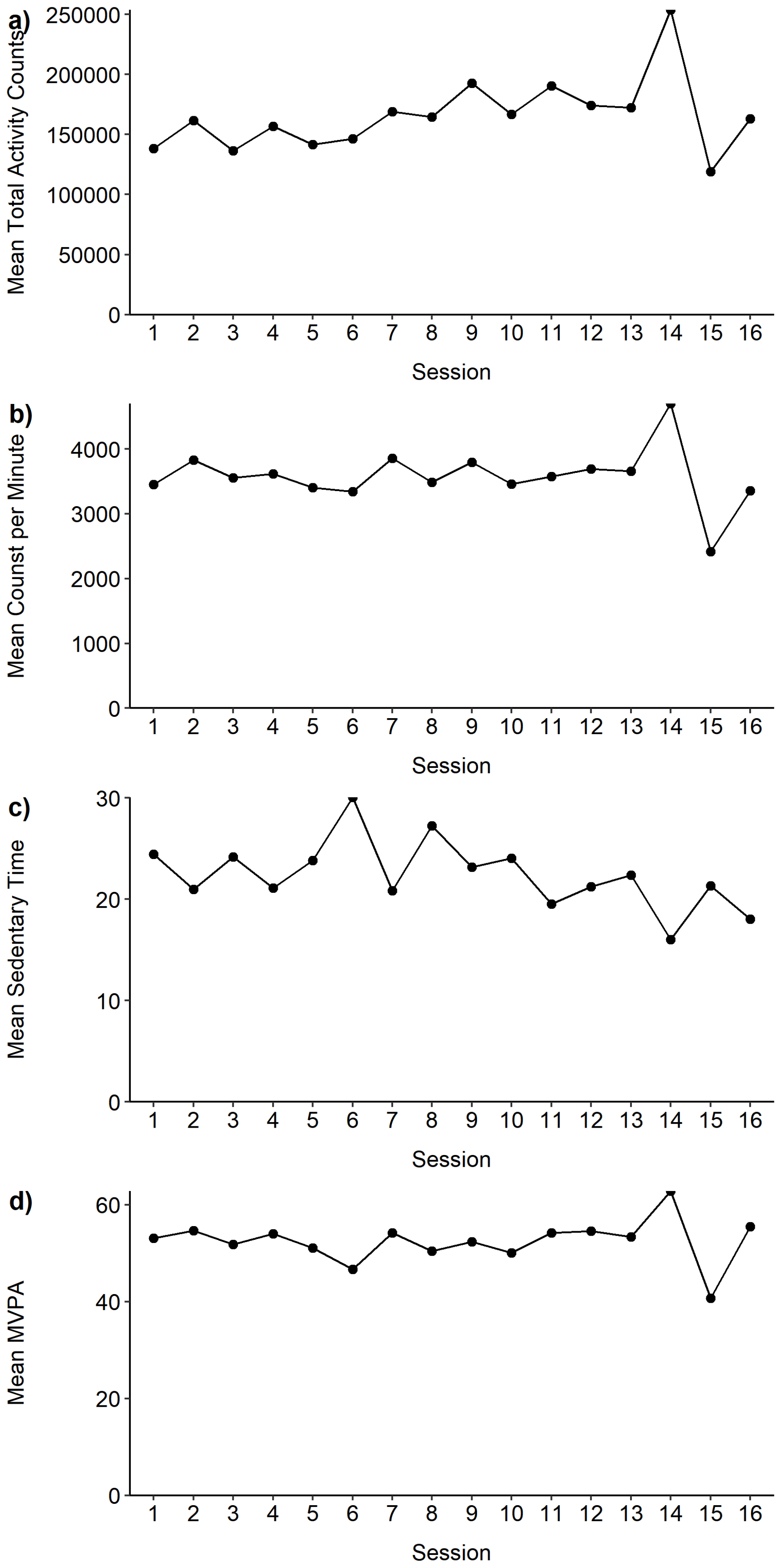

Figure 6-2 Mean intervention activity for all participants across the sixteen intervention sessions.

6.4.1.1 *Participant demographics and intervention activity by intervention site.*

A statistically significant difference in mean age between schools ($F_{(3)} = 14.359$, $p < 0.001$) was found. *Post hoc* comparisons indicated significant differences in mean age between school C ($p < 0.001$, 95%CI [0.94, 3.66]) and School D ($p < 0.001$, 95%CI [1.48, 4.82) to school A. No significant difference was found between School B and any other schools. A statistically significant difference in mean height between schools ($F_{(3)} = 4.430$, $p = 0.016$) was found. *Post hoc* comparisons indicated no significant difference in height between any schools after Bonferroni correction. A statistically significant difference in mean body mass between schools ($F_{(3)} = 5.028$, $p < 0.010$) was found. *Post hoc* comparisons indicated no significant difference in body mass between any schools after Bonferroni correction. There was no statistically significant difference in mean FM% between schools ($F_{(3)} = 3.131$, $p = 0.051$). There was no statistically significant difference in mean attendance between schools ($F_{(3)} = 2.23$, $p = 0.118$). Total mean activity, mean counts per minute, mean sedentary time and mean MVPA did not differ between schools ($F_{(3)} = 0.712$, $p = 0.557$; $F_{(3)} = 1.485$, $p = 0.251$; $F_{(3)} = 0.435$, $p = 0.730$; $F_{(3)} = 0.481$, $p = 0.700$ respectively; Figure 6-3). Mean RPE did not differ between schools ($F_{(3)} = 0.48$, $p = 0.485$).

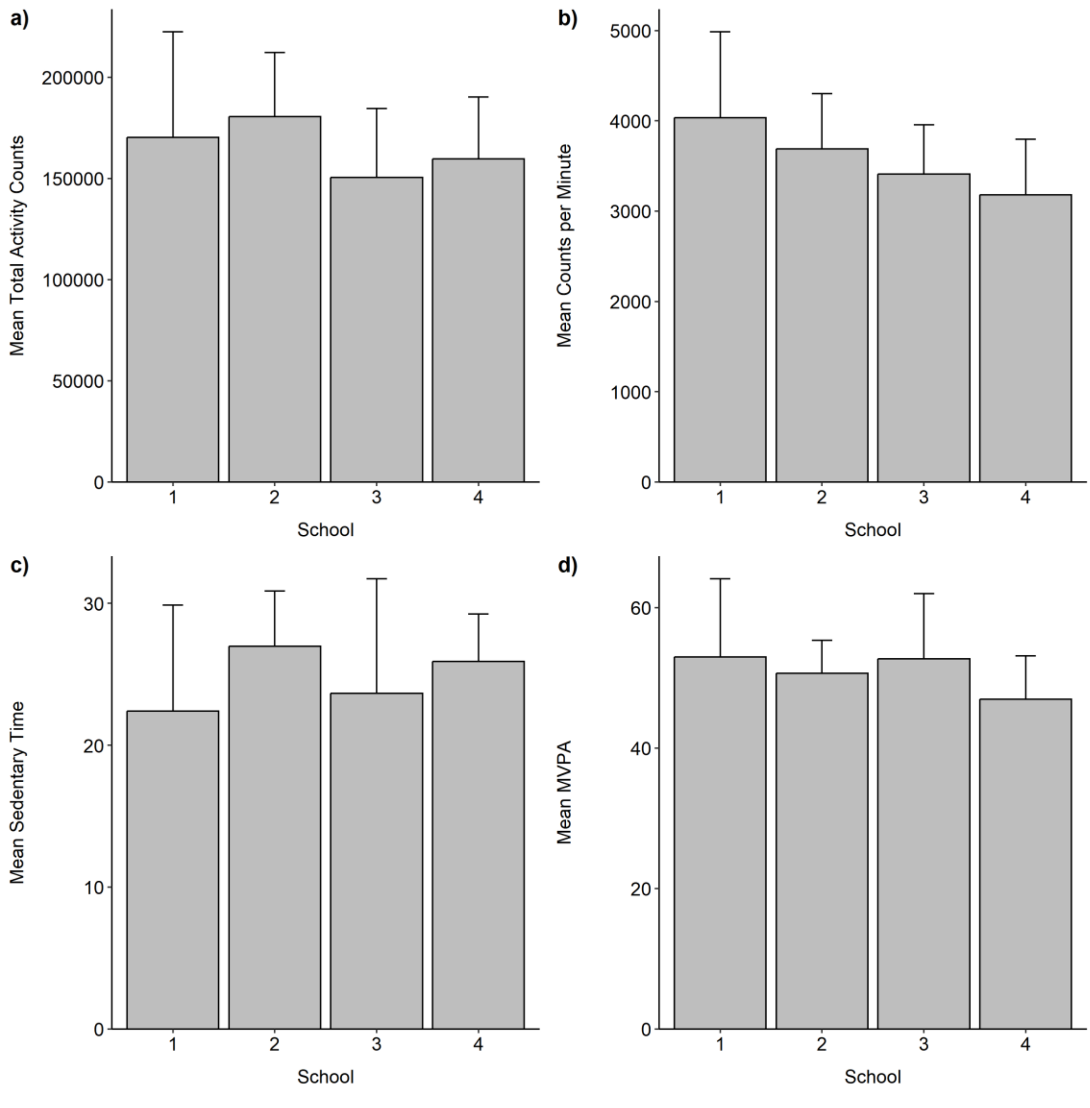

Figure 6-3 Mean intervention activity levels by school.

6.4.1.2 *Basic psychological need satisfaction and activity enjoyment beginning- to post-intervention*

Satisfaction of feelings of competency, autonomy, classmate relatedness or teacher relatedness (as measured by CARR questionnaire) did not change over the course of the intervention (Z = -1.309, p =0.191; Z = -1.865, p =0.062; Z = -0.393, p =0.694; t = 0.303, p =0.766; Figure 6-4). Enjoyment of activity sessions (as measured by PACES questionnaire) did not differ over the course of the intervention (Z =-1.614, p = 0.107; Figure 6-5).

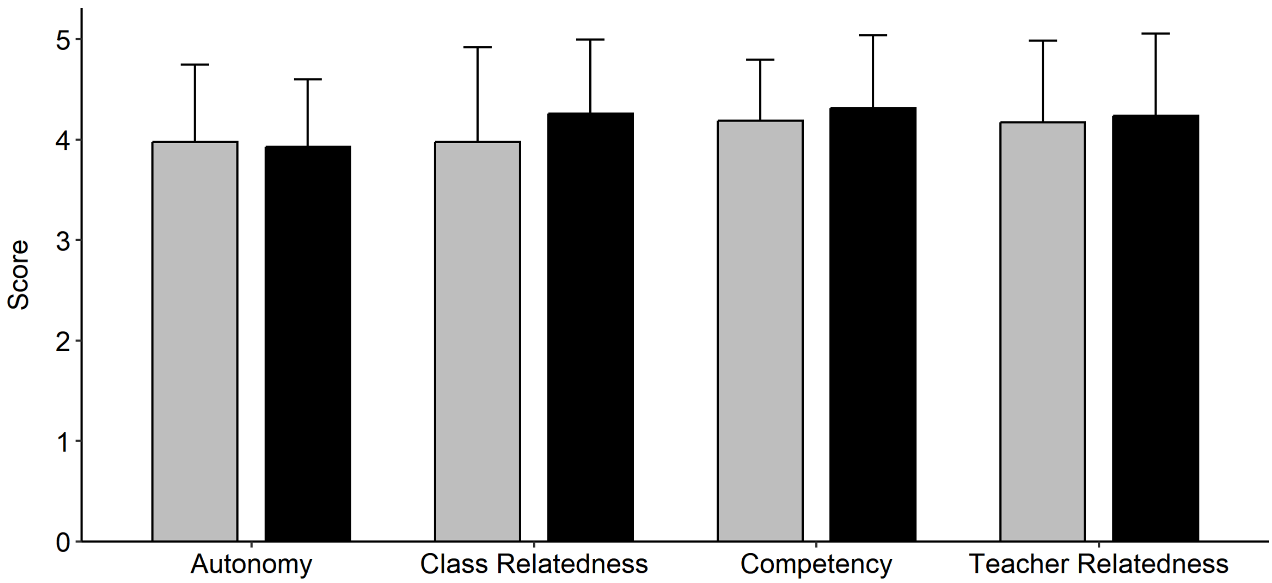

Figure 6-4 Mean CARR questionnaire responses at the beginning of the intervention period (grey) and at the end of the intervention (black).

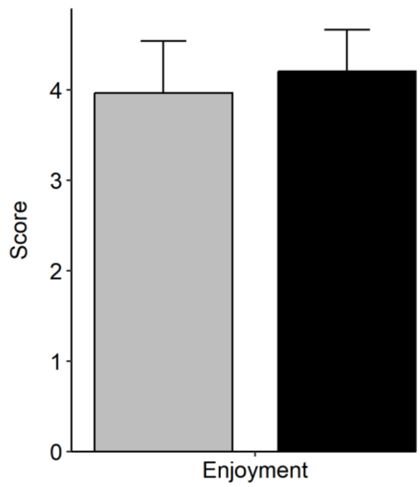

Figure 6-5 Mean PACES questionnaire responses at the beginning of the intervention period (grey) and at the end of the intervention (black).

6.4.1.3 *Relationships between intervention session activity and participant characteristics.*

There were no significant relationships between mean total activity counts and body mass, age or FM% (Figure 6-6). Mean counts per minute was negatively correlated with age (r = –0.551, p = 0.006) and FM% (r = –0.435, p = 0.038; Figure 6-7). Mean time spent in sedentary activity and MVPA during intervention sessions were not significantly correlated with body mass, age, or FM% (Figures 6-8 and 6-9). There was no difference in mean total activity counts ($t_{(22)}$ = -0.559, p = 0.582), mean counts per minute ($t_{(22)}$ = -0.843, p = 0.204), sedentary activity ($t_{(22)}$ = -0.399, p = 0.347), MVPA ($t_{(22)}$ = -0.399, p = 0.347; $t_{(22)}$ = -0.495, p = 0.313) between genders.

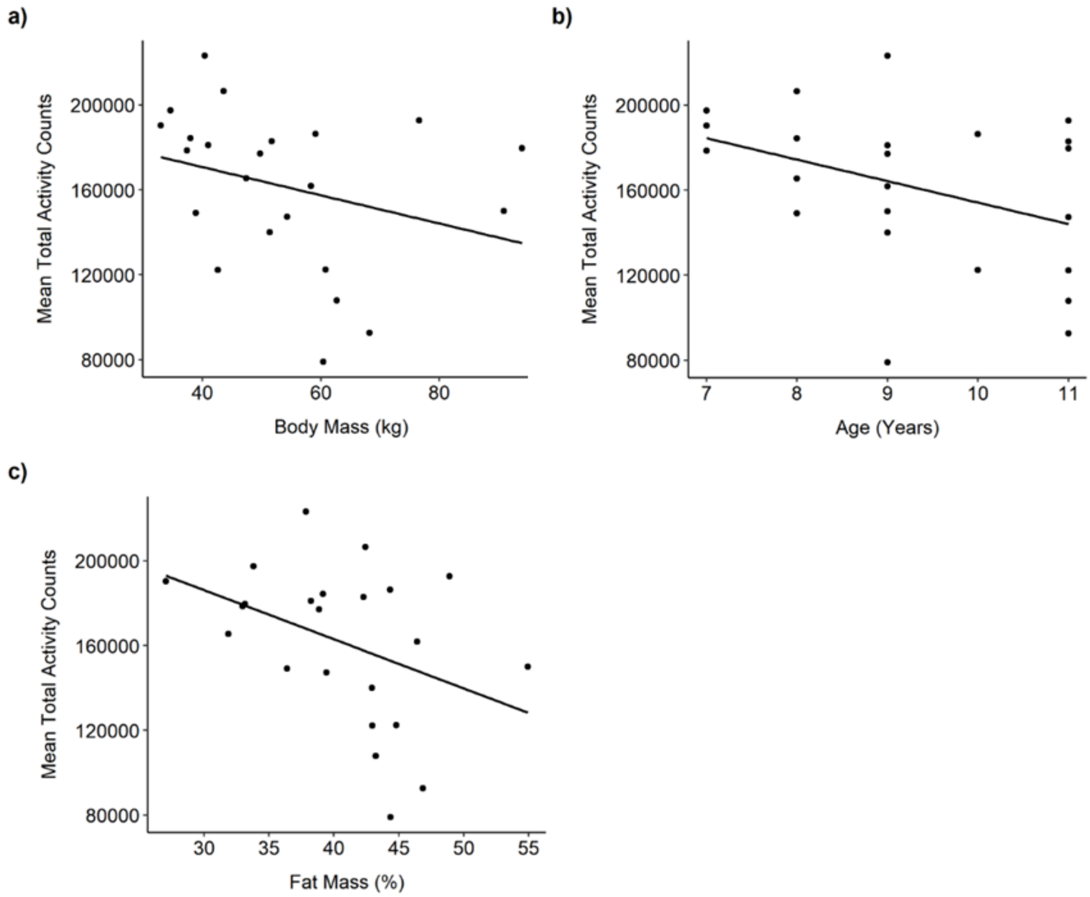

Figure 6-6 Satter plot of the relationship between total activity counts during intervention sessions and a) body mass, b) age, c) fat mass. * denotes a significant correlation

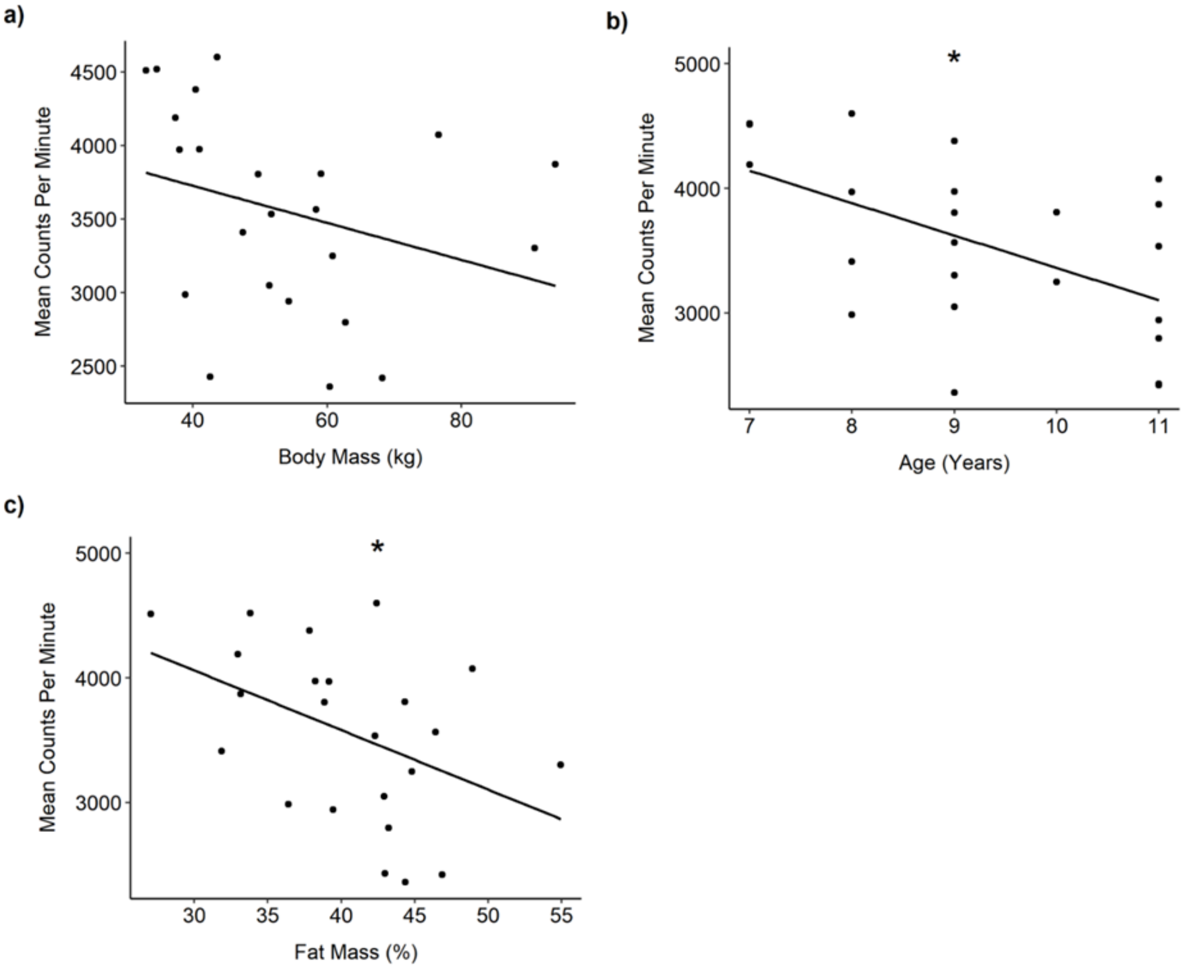

Figure 6-7 Satter plot of the relationship between counts per minute during intervention sessions and a) body mass, b) age, c) fat mass.* denotes a significant correlation

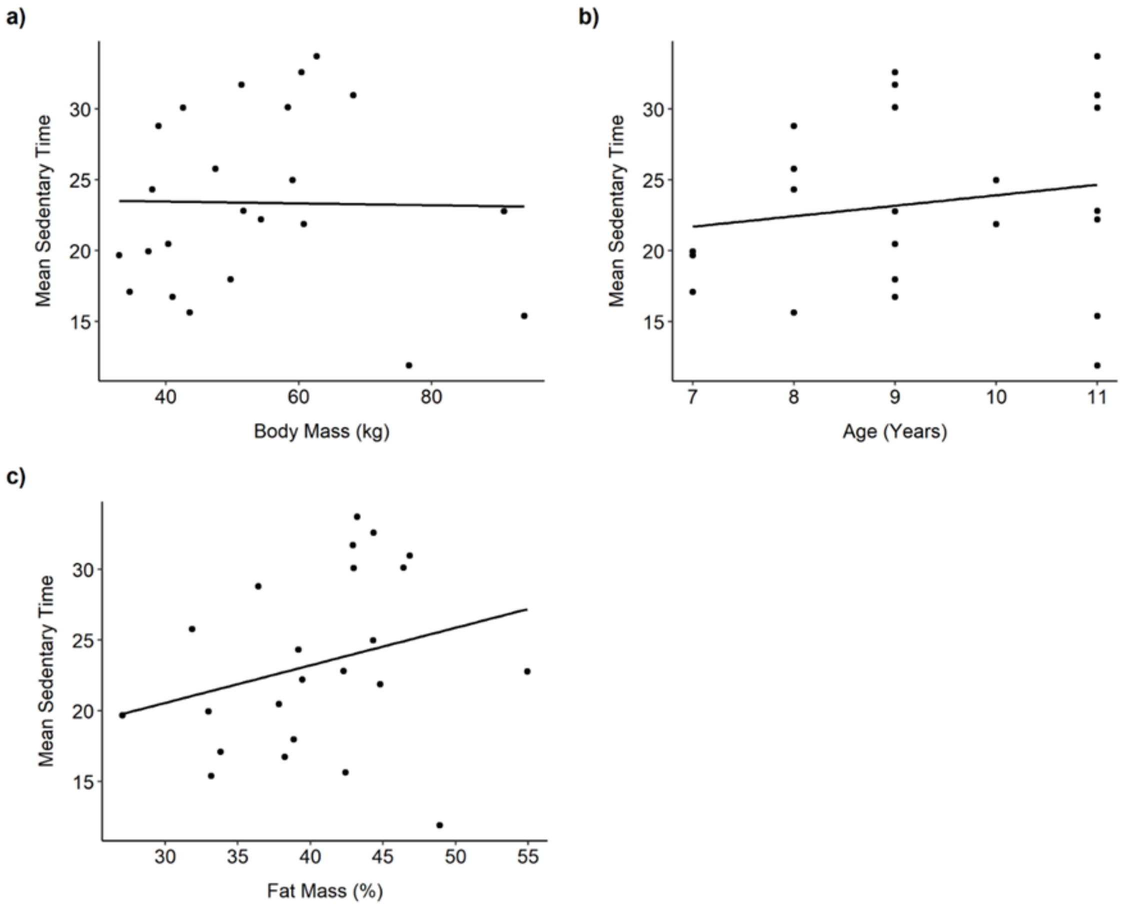

Figure 6-8 Satter plot of the relationship between sedentary time during intervention sessions and a) body mass, b) age, c) fat mass. * denotes a significant correlation

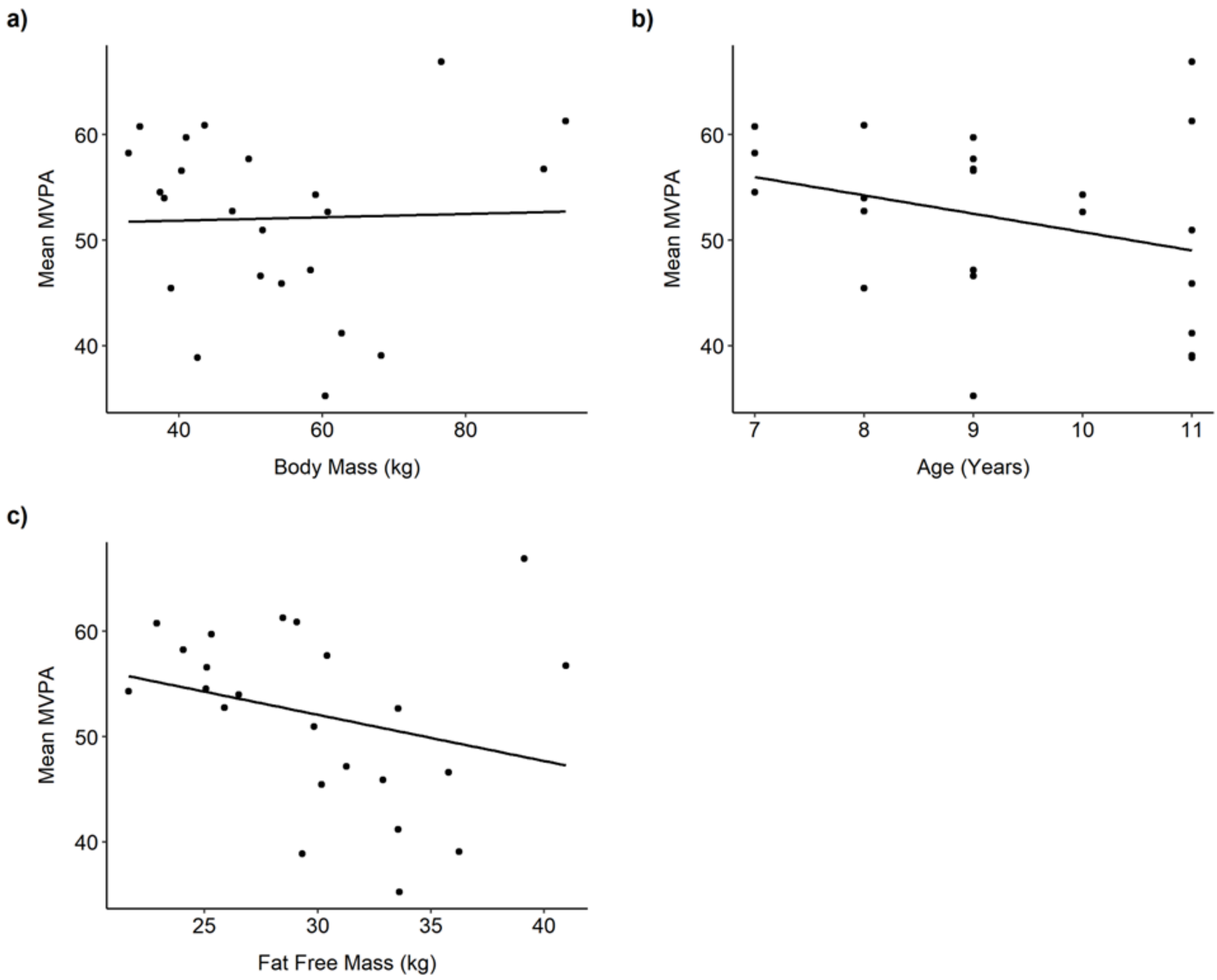

Figure 6-9 Satter plot of the relationship between moderate to vigorous physical activity (MVPA) during intervention sessions and a) body mass, b) age, c) fat mass. * denotes a significant correlation

6.4.1.4 Relationships between intervention session activity and basic psychological needs satisfaction and enjoyment.

Mean total activity counts were significantly positively correlated with enjoyment (r = 0.543, p = 0.016; Figure 6-10). Similarly, mean counts per minute were also significantly positively correlated with enjoyment (r = 0.496, p = 0.031, Figure 6-11). Mean time spent in sedentary activity was significantly negatively correlated with feelings of competency (r = -0.520, p =0.019; Figure 6-12). MVPA was not significantly correlated with basic psychological needs (BPN) satisfaction or enjoyment (Figure 6-13).

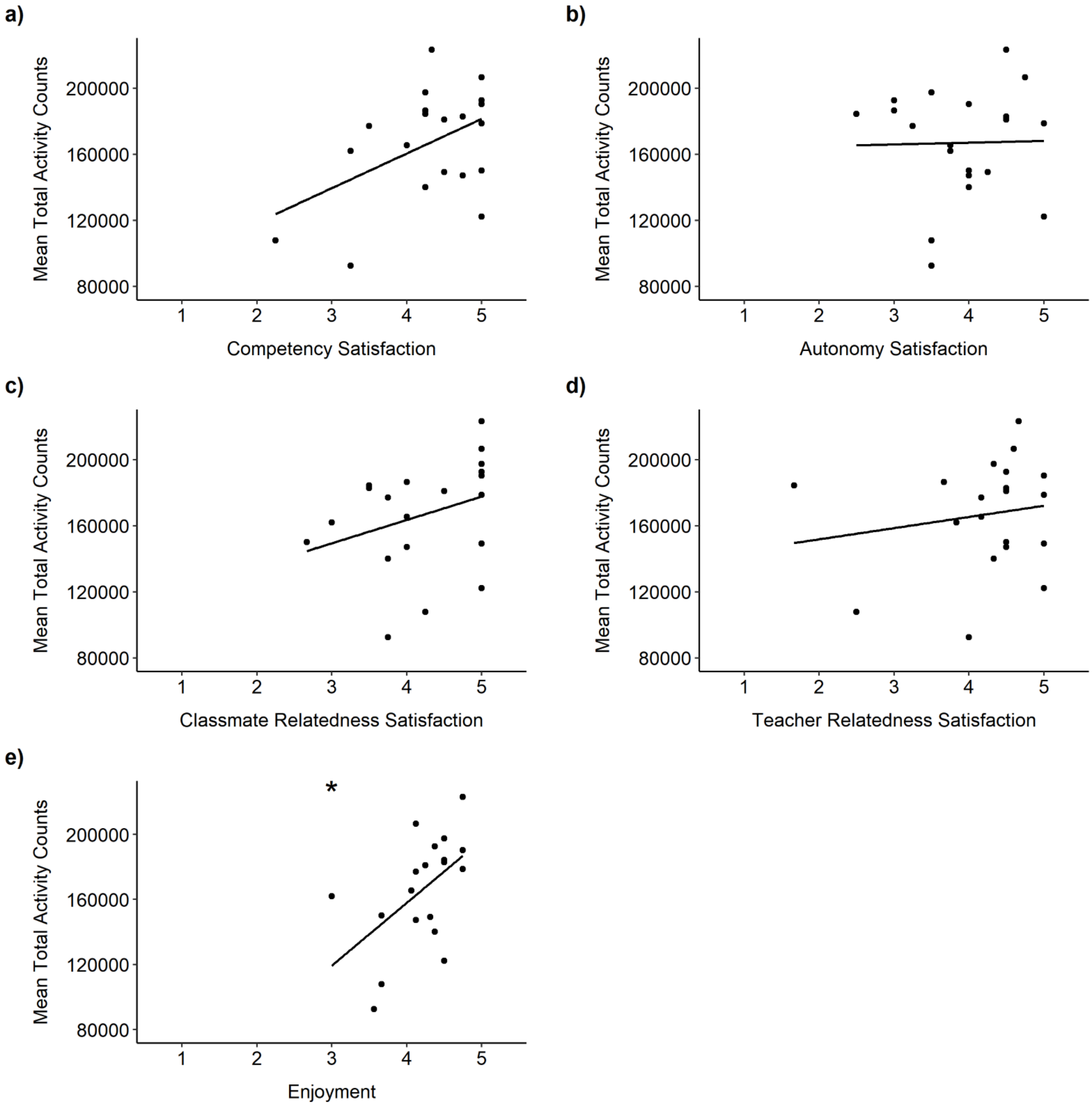

Figure 6-10 Satter plot of the relationship between total activity counts during intervention sessions and a) competency satisfaction, b) autonomy satisfaction, c) Classmate relatedness, d) teacher relatedness, and e) enjoyment.* signifies a significant correlation.

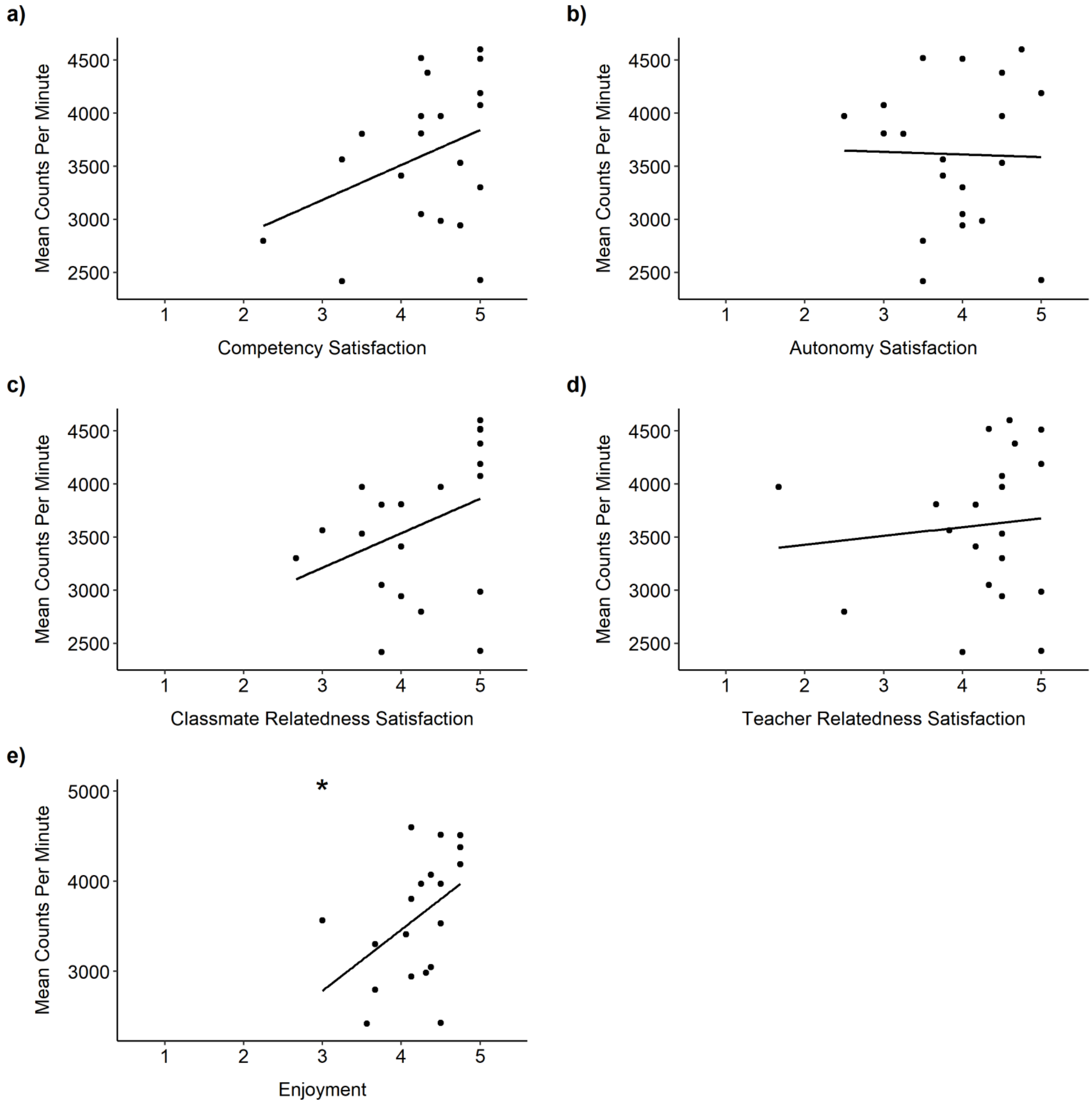

Figure 6-11 Satter plot of the relationship between counts per minute during intervention sessions and a) competency satisfaction, b) autonomy satisfaction, c) Classmate relatedness, d) teacher relatedness, and e) enjoyment.* signifies a significant correlation.

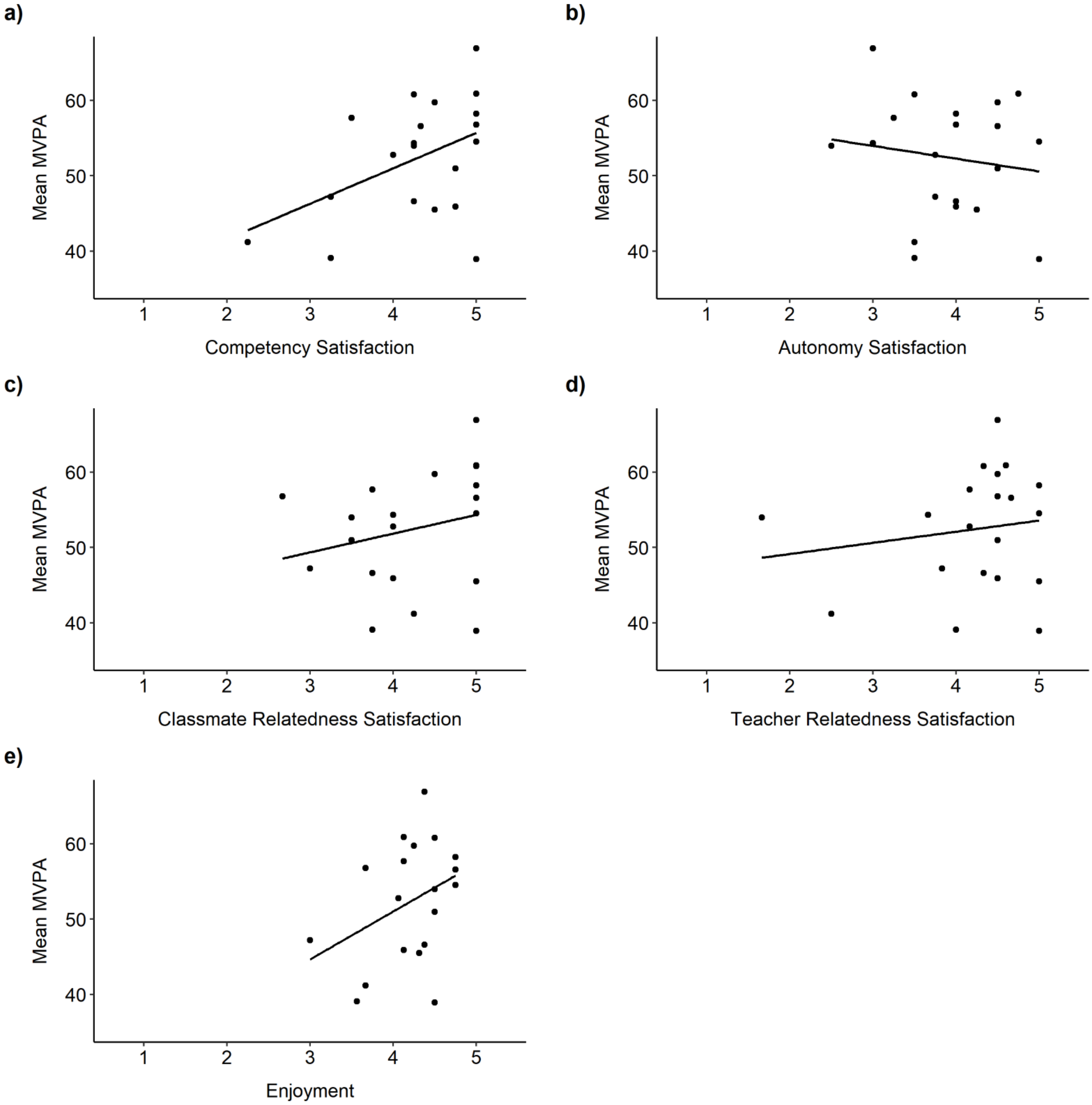

Figure 6-12 Satter plot of the relationship between moderate to vigorous physical activity (MVPA) during intervention sessions and a) competency satisfaction, b) autonomy satisfaction, c) Classmate relatedness, d) teacher relatedness, and e) enjoyment.* signifies a significant correlation

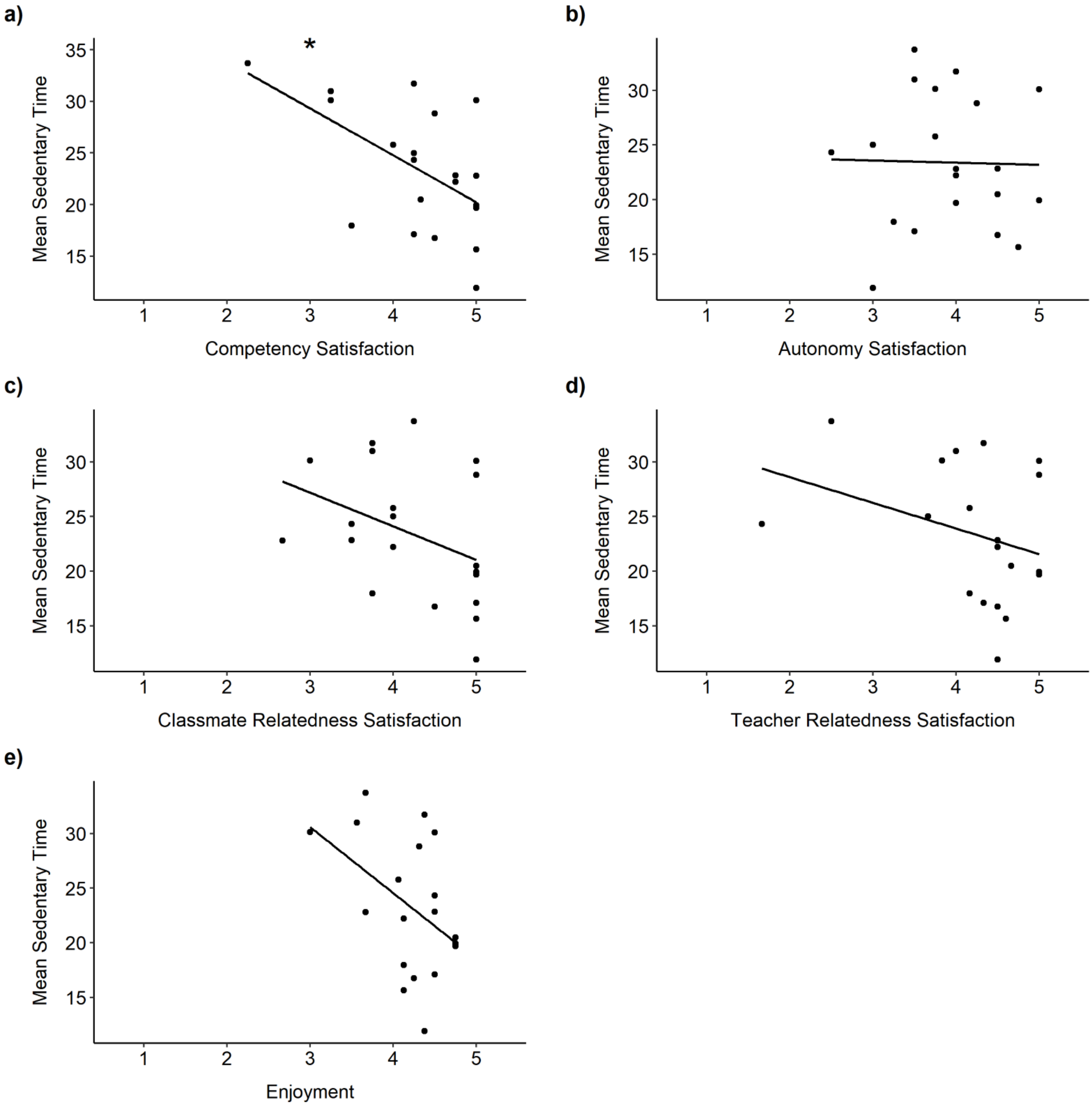

Figure 6-13 Satter plot of the relationship between sedentary time during intervention sessions and a) competency satisfaction, b) autonomy satisfaction, c) Classmate relatedness, d) teacher relatedness, and e) enjoyment.* signifies a significant correlation

6.4.2 Body Composition

There was no significant difference in body mass at pre-intervention between the experimental group and the control group (p= 0.860). There was a significant main effect of time for body mass (Table 6-4). There was no significant main effect of group on body mass (Table 6-4). There was a significant group by time effect for body mass (Table 6-4). *Post hoc* tests revealed the control group to significantly increase body mass pre- to post-intervention (p = 0.002, 95% CI [0.011, 0.055]), post-intervention to follow-up (p < 0.001, 95% CI [0.016, 0.048]), and pre-intervention to follow-up (p < 0.001, 95% CI [0.041, 0.089]). *Post hoc* tests revealed the experimental group did not significantly increase body mass pre- to post-intervention (p = 1.00, 95% CI [-0.16, 0.020]) but did significantly increase body mass post-intervention to follow (p < 0.001, 95% CI [0.0189, 0.044]) resulting in an overall increase in body mass in the experimental group pre-intervention to follow-up (p < 0.001, 95% CI [0.012, 0.053]). There were no significant differences between the experimental and control group body mass at post-intervention (p = 0.614, 95% CI [-0.144, 0.240]) or follow-up (p = 0.610, 95% CI [-0.146, 0.244]).

There was no significant difference in height at baseline between the experimental group and the control group (p = 405). There was a significant effect of time for height (Table 6-4). *Post hoc* tests revealed height significantly increased pre- to postintervention (p < 0.001, 95% CI [0.006, 0.011]), post-intervention to follow-up (p < 0.001, 95% CI [0.008, 0.016]), and pre-intervention to follow-up (p < 0.001, 95% CI [0.016, 0.024]). There was no significant group by time effect for height (Table 6-4).

There was no significant difference in BMI Z-score at baseline between the experimental group and the control group (p = 0.316). There was no significant effect of time for BMI Z-score (Table 6-4). There was no main effect of group for BMI Z-score (Table 6-4). There was a significant group by time effect for FFMkg (Table 6-4). *Post hoc* tests revealed that the control group had no change in BMI Z-score between pre- and post-intervention (p = 0.197, 95% CI [-0.041, 0.292]), or post-intervention to follow-up (p = 0.0.731, 95% CI [-0.065, 0.180]), but the control did have a significant increase in BMI Z-score over the study period pre-intervention to follow-up (p = 0.008, 95% CI [0.041, 0.325]; Figure 6-14). The experimental group had a significant decrease in BMI Z-score pre- to post-intervention (p = 0.001, 95% CI [-0.651, -0.076]), with no significant change in BMI Z-score post-intervention to follow-up (p = 1.00, 95% CI [-0.127, 0.075]), resulting in an overall significant decrease in BMI Z-score pre-intervention to follow-up (p < 0.001, 95% CI [-0.305, -0.071]; Figure 6-14). There were no significant differences between the experimental and control group BMI Z-score at post-intervention (p = 0.761, 95% CI [-0.477, 0.646]) or follow-up (p = 0.668, 95% CI [-0.431, 0.663]).

There was no significant difference in FFMkg at baseline between the experimental group and the control group (p = 0.719). There was a significant effect of time for FFMkg (Table 6-4). *Post hoc* tests revealed FFMkg significantly increased pre- to postintervention (p = 0.008, 95% CI [0.137, 1.074), post-intervention to follow-up (p < 0.001, 95% CI [0.477, 1.353]), and pre-intervention to follow-up (p < 0.001, 95% CI [1.126, 1.915]). There was no significant effect of group for FFMkg (Table 6-4). There was no significant group by time effect for FFMkg (Table 6-4).

There was no significant difference in FM% at baseline between the experimental group and the control group (p =0.768). There was no significant effect of time for FM% (Table 6-4). There was no significant effect of group for FM% (Table 6-4). There was a significant group by time effect for FM% (Table 6-4). *Post hoc* tests revealed no significant difference in the control group pre- to post-intervention (p = 0.622, 95% CI [-2.230, 0.727]), post-intervention to follow-up (p = 1.00, 95% CI [-1.496, 1.344]), or pre-intervention to follow-up (p = 0.582, 95% CI [-2.407, 0.752]). *Post hoc* tests revealed no significant difference in the experimental group pre- to post-intervention (p = 0.115 95% CI [-0.177, 2.268]), post-intervention to follow-up (p = 1.00, 95% CI [-1.155, 1.194]), or pre-intervention to follow-up (p = 0.143, 95% CI [-0.42, 2.371]). There were no significant differences between the experimental and control group FM% at post-intervention (p = 0.665, 95% CI [-6.073, 3.931]), or follow-up (p = 0.643, 95% CI [-6.254, 3.921]).

Table 6-4 Pre-intervention, Post-intervention, and Follow-up Mean ± SD of body composition measures and main ANOVA effects of time and group for the experimental and control group.

	Body Mass (kg)		**Height (m)**		**BMI Z-Score**		**FFM (kg)**		**FM (%)**	
	EXP	***CON***	***EXP***	***CON***	***EXP***	***CON***	***EXP***	***CON***	***EXP***	***CON***
Pre	50.71 ± 14.71	51.35 ± 13.73	1.44 ± 0.09	1.46 ± 0.08	2.50 ± 0.73	2.25 ± 0.63	29.42 ± 5.32	30.06 ± 4.27	40.46 ± 6.45	39.74 ± 7.24
Post	50.93 ± 15.52	52.88 ± 13.23	1.45 ± 0.09	1.47 ± 0.08	2.29 ± 0.86	2.37 ± 0.56	29.99 ± 5.61	30.69 ± 4.30	39.42 ± 6.81	40.49 ± 6.78
Follow	52.55 ± 16.12	54.66 ± 13.75	1.46 ± 0.09	1.48 ± 0.08	2.31 ± 0.81	2.43 ± 0.61	30.90 ± 5.55	31.62 ± 4.27	39.4 ± 6.76	40.57 ± 7.14
Time (f, *p*)	61.63, *<0.001 **		112.2, *<0.001**		0.897, *0.413*		39.86, *<0.001 **		0.083,0 *.920*	
Group (f, *p*)	0.162, *0.69*		0.546*, 0.465*		0.005*, 0.945*		0.144*, 0.707*		0.043, *0.837*	
Group x Time (f, *p*)	6.805, *0.014**		2.557, *0.099*		15.42, *<0.001 **		0.022*, 0.978*		3.89, *0.026**	

Note: CON= Control group; EXP = Experimental Group; FFM Fat Free Mass; FM = Fat mass

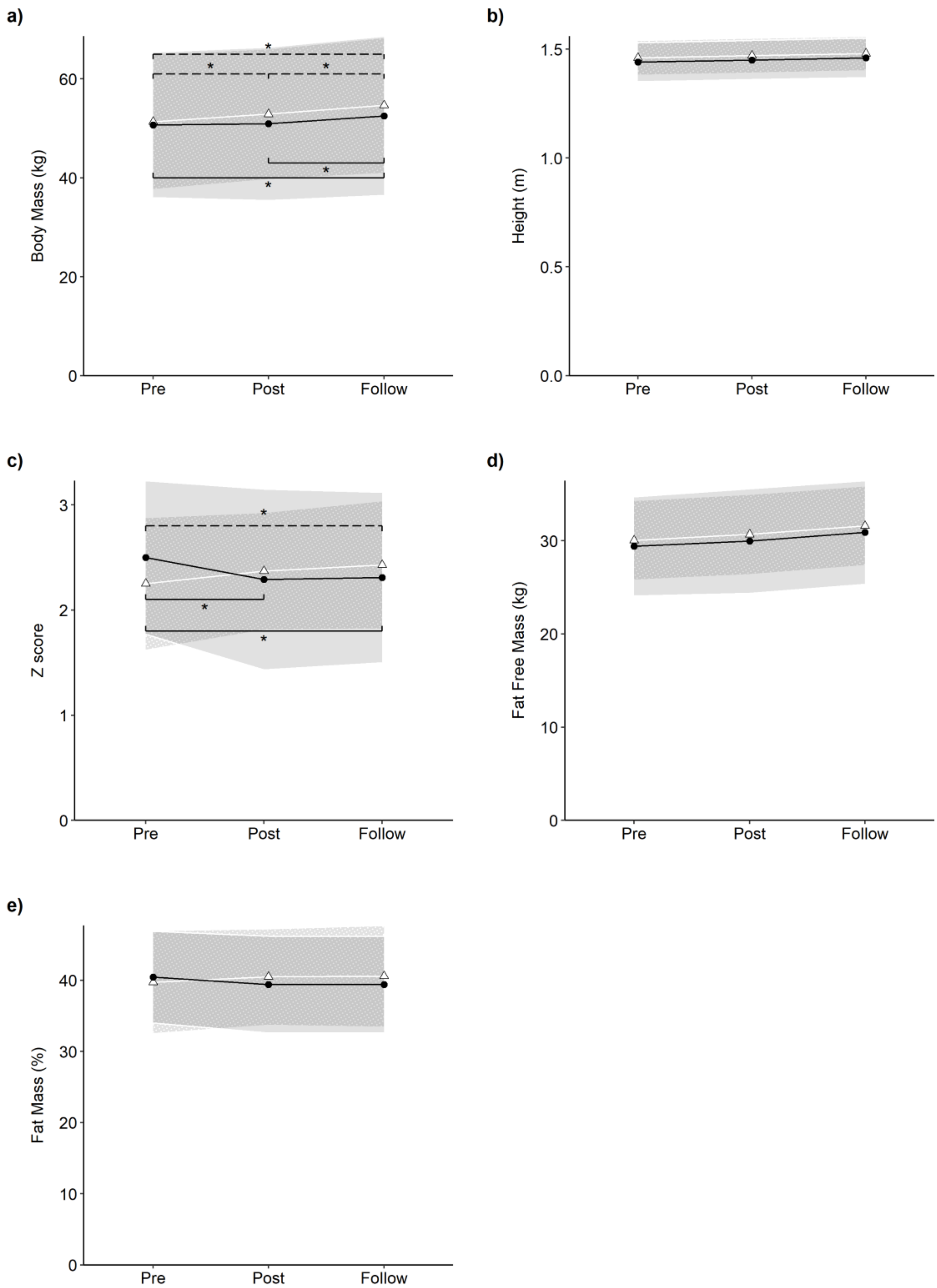

Figure 6-14 Pre-intervention, Post-intervention, and Follow-up Mean ± SD of body composition measures a) Body Mass; b) Height; c) Z-score; d) Fat Free Mass; e) Fat Mass, for the experimental (•) and control group (Δ). * on a dashed line denotes a significant change over time for the control group. * on a solid line denotes a significant change over time for the control group.

6.4.3 Physical well-being

6.4.3.1 Pain and Health-related quality of life

There was no significant difference in Pain Now at baseline between the experimental group and control group (p = 0.566). There was a significant effect of time for Pain Now (Table 6-5). *Post hoc* tests showed no significant differences between time points in the control group for Pain Now (pre-to-post intervention: Z = -1.20, p = 0.23; post-to-follow-up intervention: Z = -1.73, p = 0.24; pre-intervention to follow-up: Z = -1.96, p = 0.05). There was no significant effect of group for Pain Now (Table 6-5)

There was no significant difference in Worst Pain at baseline between the experimental group and control group (p = 0.213). There was no significant effect of time for Worst Pain. There was no significant effect of group for Worst Pain.

There was no significant difference in physical HRQoL at baseline between the experimental group and control group (p = 0.984). There was no significant effect of time for HRQoL. There was no significant effect of group for physical HRQoL.

Table 6-5 Pre-intervention, Post-intervention, and Follow-up Mean ± SD of pain and physical domain health-related quality of life score for the experimental and control group and non-parametric test result.

	Pain Now		**Worst Pain**		**Physical HRQoL**	
	EXP	***CON***	***EXP***	***CON***	***EXP***	***CON***
Pre	10.32 ± 21.12	15.00 ± 25.87	22.21 ± 27.82	20.83 ± 21.58	75.82 ± 16.23	77.34 ± 13.00
Post	14.84 ± 16.27	23.17 ± 20.52	36.74 ± 27.88	33.33 ± 33.78	81.91 ± 15.22	80.21 ± 12.50
Follow	16.05 ± 30.00	27.33 ± 25.95	27.68 ± 34.66	48.58 ± 29.40	81.09 ± 19.56	72.54 ± 18.98
Effect of Time (f, p)	Exp = 2.28, *0.32* Con = 7.30, *0.03**		Exp = 5.16, *0.08* Con = 4.98, *0.08*		Exp = 4.79, *0.09* Con = 1.515, *0.47*	
Effect of Group	Z = 0.566, p =0.626		Z = 0.-0.447, p =0.655		Z = -2.011, p =0.160	

Note: CON= Control group; EXP = Experimental Group; HRQoL = Health-related quality of life.

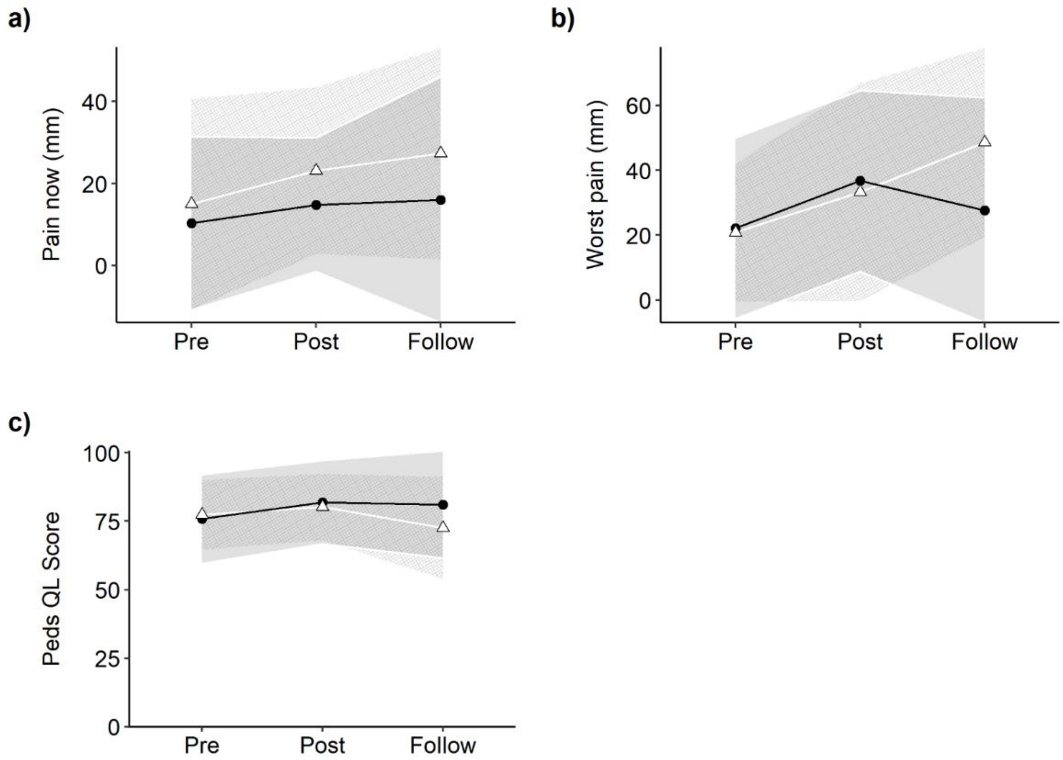

Figure 6-15 Pre-intervention, Post-intervention, and Follow-up Mean ± SD pain and physical domain health-related quality of life score a) pain now; b) worst pain in last 7 days; c) physical domain health-related quality of life score) for the experimental (•) and control group (Δ). * on a dashed line denotes a significant change over time for the control group. *on a solid line denotes a significant change over time for the control group.

6.4.3.2 Physical activity

The return of accelerometers at each time point with valid data (defined as a total of 10 hours per day, including two weekdays and one weekend day) was poor in both the experimental and control groups. The following analysis is based on eight experimental participants and three control group participants.

There was no significant difference in sedentary time% at baseline between the experimental group and control group (p= 0.248). There was a significant effect of time for sedentary time% (Table 6-6). *Post hoc* tests revealed a significant decrease in sedentary time post-intervention to follow-up (p = 0.014, 95% CI [-18.966, -2.225]), there was no significant difference between pre-intervention and post-intervention (p = 0.732, 95% CI [-3.971, 9.845]) or pre-intervention to follow-up (p = 0.035, 95% CI [-14.796, -0.521]). There was no significant effect of group for sedentary time% (Table 6-6). There was no significant group by time effect for sedentary time%**.**

The experimental group had significantly lower MVPA time than the control *group at baseline* ($t_{(9)}$ = 4.472, p = 0.002). There was no significant effect of time for MVPA% (Table 6-6). There was no significant effect of group for MVPA%. There was no significant group by time effect for MVPA%.

There was no significant difference in total vector magnitude counts at baseline between the experimental group and control group (p = 0.257). There was no significant effect of time for total vector magnitude counts.

There was no significant effect of group for total vector magnitude counts. There was no significant group by time effect for total vector magnitude counts.

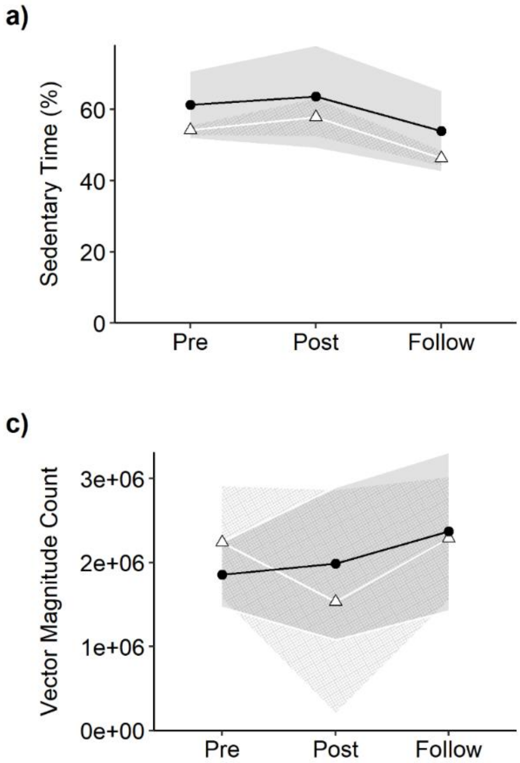

Figure 6-16 Pre-intervention, Post-intervention, and Follow-up Mean ± SD for physical activity a) sedentary time; b) moderate to vigorous physical activity; c) total vector magnitude counts) for the experimental (•) and control group (Δ). * denotes a significant difference between groups at time point.

Table 6-6 Pre-intervention, Post-intervention, and Follow-up Mean ± SD of physical activity measures and main ANOVA effects of time and group for the experimental and control group.

	Sedentary (%)		MVPA (%)		Vector Magnitude Count	
	EXP	***CON***	***EXP***	***CON***	***EXP***	***CON***
Pre	61.35 ± 9.60	54.25 ± 1.57	14.02 ± 9.59	29.91 ± 1.84	1853329.34 ± 388987.70	2237935.8 ± 678511.28
Post	63.62 ± 14.55	57.86 ± 5.61	24.44 ± 8.73	26.90 ± 4.54	1987744.95 ± 908944.72	1534017.63 ± 1339357.51
Follow	53.95 ± 11.54	46.34 ± 2.31	29.83 ± 9.74	37.44 ± 3.58	2367892.61 ± 942588.71	2287002.83 ± 738237.96
Time (f, *p*)	9.160, *0.002* *		10.99, *0.011* *		1.430, *0.276*	
Group (f, *p*)	1.046, *0.337*		4.549, *0.062*		0.015, *0.905*	
Group x Time (f, *p*)	0.072, *0.936*		0.640, *0.538*		0.793, *0.473*	

Note: CON= Control group; EXP = Experimental Group; MVPA = Moderate to vigorous physical activity. * signifies statistical significance

6.4.4 Physical function

6.4.4.1 Clinical measures of physical function

There was no significant difference in 6MTW at baseline between the experimental group and control group (p = 0.404). There was a significant effect of time for 6MTW. There was no significant effect of group 6MTW. Mean experimental group increases in 6MTW did not meet the minimal detectable change (MDC) threshold set out in Chapter 3.

There was a significant difference in TUG at baseline between the experimental group and control group (Z = -0.866, p = 0.015). A significant effect of time was observed for TUG time in the experimental group (Table 6-7). *Post hoc* tests revealed no significant differences between pre- and post-intervention TUG times in the experimental group (Z = -1.89, p = 0.059) or between post-intervention and follow-up (Z = -1.07, p = 0.285). However, there was a significant decrease in TUG time from pre-intervention to follow-up (Z = -2.104, p = 0.035) in the experimental group (Figure 6-17). Mean experimental group increases in TUG did not meet the MDC threshold set out in Chapter 3.

There was no significant difference in STS at baseline between the experimental group and control group (p = 0.153). There was a significant effect of time for STS. *Post hoc* tests revealed that STS repetitions in the experimental group were significantly greater at post-intervention (Z = -2.73, p = 0.006) and at follow-up (Z = -2.75, p = 0.006) compared to pre-intervention. Additionally, STS repetitions in the control group were significantly fewer at post-intervention (Z = -2.137, p = 0.030) and follow-up (Z = -2.24, p = 0.025) compared to pre-intervention. Mean experimental group increases in STS did not meet the MDC threshold set out in Chapter 3.

There was no significant difference in SLS Eyes Open at baseline between the experimental group and control group (p = 0.446). There was a significant effect of time for SLS Eyes Open (Table 6-7). *Post hoc* tests revealed a significant increase in SLS with eyes open time pre- to post-intervention (p = 0.010, 95% CI [-0.134, 1.202]), there were no significant differences between post-intervention and follow-up (p = 0.214, 95% CI [-1.48, -0.977]) and pre-intervention and follow-up (p = 0.608, 95% CI [-0.752, 0.242]). There was no significant effect of group for SLS Eyes Open (Table 6-7). There was no significant group by time effect for SLS Eyes Open. Mean experimental group increases in SLS did not meet the MDC threshold set out in Chapter 3.

There was no significant difference in SLS Eyes Closed at baseline between the experimental group and control group (p = 0.338). There was no significant effect of time for SLS Eyes Closed (Table 6-7). There was no significant effect of group for SLS Eyes Closed (Table 6-7). There was no significant group by time effect for SLS Eyes Closed. Mean experimental group increases in SLS eyes closed did not meet the MDC threshold set out in Chapter 3.

Table 6-7 Pre-intervention, Post-intervention, and Follow-up Mean ± SD of clinical measures of physical function and main ANOVA effects of time and group for the experimental and control group, and non-parametric results.

	6MTW (m)		STS (n)		TUG (s)		SLSEyes (s)		SLSClosed (s)	
	EXP	***CON***	***EXP***	***CON***	***EXP***	***CON***	***EXP***	***CON***	***EXP***	***CON***
Pre	518.4 ± 41.46	503.1 ± 61.01	30.42 ± 5.05	33.88 ± 8.340	5.25 ± 0.58	4.39 ± 1.24	44.26 ± 37.17	36.1 ± 32.12	6.96 ± 6.5	5.67 ± 6.51
Post	519.8 ± 59.63	542.0 ± 43.66	33.37 ± 4.50	31.23 ± 10.86	4.50 ± 0.46	4.92 ± 1.04	74.09 ± 89.67	85.52 ± 64.64	9.45 ± 12.45	15.04 ± 21.11
Follow	522.2 ± 56.25	527.3 ± 51.22	33.89 ± 4.82	28.92 ± 10.78	4.61 ± 0.75	4.50 ± 0.62	67.65 ± 53.55	66.57 ± 66.06	10.54 ± 9.98	13.77 ± 12.67
	Ŧ		Ŧ		Ŧ					
Time (f, *P*)	Exp = 0.421, p = *0.810*		Exp = 7.91, p = *0.019**		Exp = 17.33, p < *0.001**		3.158, *0.008**		3.158, *0.057*	
	Con = 1.85, p = *0.397*		Con = 5.22, p = *0.074*		Con = 4.31, p = *0.12*					
Group (f, *P*)	Z = 0.077, p = *0.748*		Z = 0.249, p = *0.621*		Z = 0.720, p = *0.403*		0.225, *0.639*		0.543, *0.989*	
Group x Time (f, *P*)							0.97, *0.38*		0.53, *0.590*	

Note: CON= Control group; EXP = Experimental Group; 6MTW = Six Minute Timed Walk; STS = Sit To Stand; TUG = Timed up and go; SLSEyes = Single Leg Stance with eyes open; SLSClosed = Single Leg Stance with eyes closed; Ŧ = non-parametric test result * denotes statistical significance

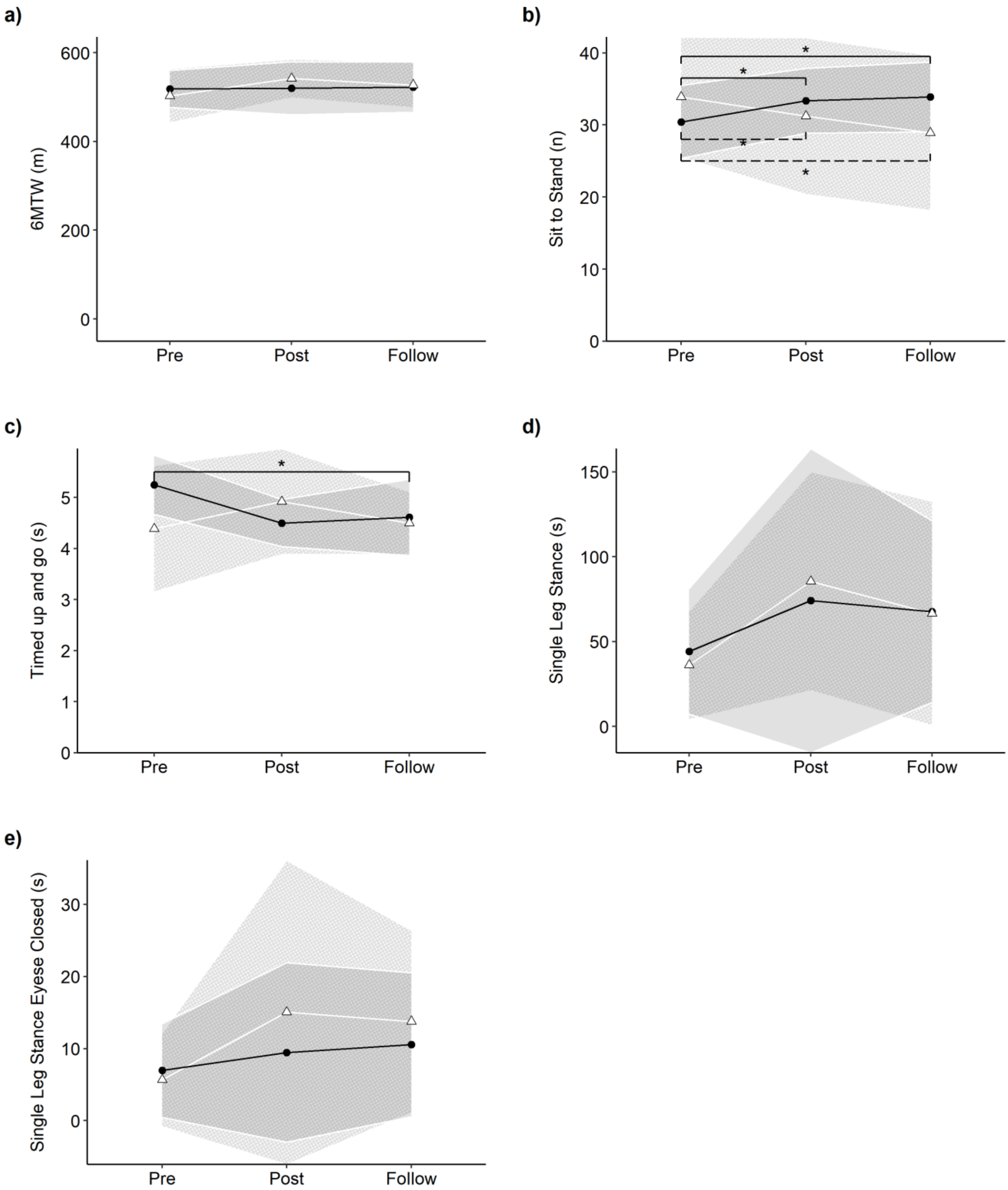

Figure 6-17 Pre-intervention, Post-intervention, and Follow-up Mean ± SD for clinical measures of physical function a) six minute timed walk distance; b) sit to stand; c) timed up and go; d) single leg stance time; d) single leg stance eyes closed time for the experimental (•) and control group (Δ). * over a dashed line denotes a significant change over time for the control group. * on a dashed line denotes a significant change over time for the control group. * on a solid line denotes a significant change over time for the control group.

6.4.4.2 Muscular strength

There was no significant difference in ankle plantar flexion at baseline between the experimental group and control group ($p = 0.248$). There was no significant effect of time for ankle plantar flexion. There was no significant effect of group for ankle plantar flexion. There was no significant group by time effect for ankle plantar flexion. Mean experimental group increases in ankle plantarflexion did not meet the MDC threshold set out in Chapter 3.

There was no significant difference in ankle dorsiflexion at baseline between the experimental group and control group ($p = 0.596$). There was a significant effect of time for ankle dorsiflexion. *Post hoc* tests revealed there was a significant increase in ankle dorsiflexion strength pre-intervention to post-intervention ($p < 0.001$, 95%CI [0.752, 2.950]), there was no significant difference in ankle dorsiflexion strength pre-intervention to follow-up ($p = 1$, 95%CI [-1.708, 1.786]) or post-intervention to follow-up ($p = 0.046$, 95%CI [0.030, 3.750]). There was a significant effect of group for ankle dorsiflexion. There was no significant group by time effect for ankle dorsiflexion. Mean experimental group increases in ankle dorsiflexion did not meet the MDC threshold set out in Chapter 3.

There was no significant difference in knee extension at baseline between the experimental group and control group ($p = 0.891$). There was no significant effect of time for knee extension. There was no significant effect of group for knee extension. There was no significant group by time effect for knee extension. Mean experimental group increases in knee extension did not meet the MDC threshold set out in Chapter 3.

There was no significant difference in knee flexion at baseline between the experimental group and control group ($p = 0.770$). There was no significant effect of time for knee flexion. There was no significant effect of group for knee flexion. There was no significant group by time effect for knee flexion. Mean experimental group increases in knee flexion did not meet the MDC threshold set out in Chapter 3.

There was no significant difference in hip extension at baseline between the experimental group and control group ($p = 1.00$). There was no significant effect of time for hip extension. There was no significant effect of group for hip extension. There was no significant group by time effect for hip extension. Mean experimental group increases in hip extension did meet the +5.47Nm MDC threshold set out in Chapter 3.

There was no significant difference in hip flexion at baseline between the experimental group and control group ($p = 1.00$). There was no significant effect of time for hip flexion. There was no significant effect of group for hip flexion**.** There was a significant group by time effect for hip flexion. *Post hoc* tests revealed no significant differences in hip flexion strength for the control group pre- to post-intervention ($p = 0.194$, 95%CI [-8.044, 1.119]), post-intervention to follow-up ($p = 1.00$, 95%CI [-6.425, 6.306]) or pre-intervention to follow-up ($p = 0.103$, 95%CI [-0.725, 10.864]). Changes in the experimental group post-intervention to follow-up ($p = 1.00$, 95%CI [-4.932, 5.886]) and pre-intervention to follow-up ($p = 0.103$, 95%CI [-0.725, 10.864]) were not significant. The experimental group had a significant increase in hip flexion strength pre- to post-intervention ($p = 0.017$, 95%CI [0.699, 8.486]). There were no significant differences between groups at post-intervention ($p = 0.155$, 95%CI [-2.091, 12.550]) or follow-up ($p = 0.150$, 95%CI [-2.199, 13.703]). Mean experimental group increases in hip flexion did not meet the MDC threshold set out in Chapter 3.

There was no significant difference in hip abduction at baseline between the experimental group and control group (p = 0.199). There was a significant effect of time for hip abduction. *Post hoc* tests revealed no significant changes pre-intervention to post-intervention (p = 0.150, 95%CI [-2.199, 13.703]), pre-intervention to follow-up (p = 0.150, 95%CI [-2.199, 13.703]) or post-intervention to follow-up (p = 0.150, 95%CI [-2.199, 13.703]). There was no significant effect of group for hip abduction**.** There was no significant group by time effect for hip abduction. Mean experimental group increases in hip abduction met the +6.69Nm MDC threshold set out in Chapter 3.

There was no significant difference in hip adduction at baseline between the experimental group and control group (p = 0.846). There was no significant effect of time for hip adduction. There was no significant effect of group for hip adduction. There was a significant group by time effect for hip adduction. *Post hoc* tests revealed the control group to have no significant changes pre-intervention to post-intervention (p = 0.182, 95%CI [--6.223, 0.825]), pre-intervention to follow-up (p = 1.00, 95% CI [-6.067, 3.414]) or post-intervention to follow-up (p = 1.00, 95%CI [-3.632, 6.377]). The experimental group had a significant increase in hip adduction strength pre- to post-intervention (p = 0.002, 95%CI [1.801, 8.362]) and pre-intervention to follow-up (p = 0.002, 95%CI [2.231, 11.058]) with no significant increases post-intervention to follow-up (p = 1.00, 95%CI [-3.096, 6.221]). Mean experimental group increases in hip adduction did not meet the MDC threshold set out in Chapter 3.

Table 6-8 Pre-intervention, Post-intervention, and Follow-up Mean ± SD of absolute strength and main ANOVA effects of time and group for the experimental and control group, and non-parametric results.

	Ankle Plantarflexion		**Ankle Dorsiflexion**		**Knee Extension**		**Knee Flexion**	
	EXP	***CON***	***EXP***	***CON***	***EXP***	***CON***	***EXP***	***CON***
Pre	31.72 ± 11.48	37.29 ± 14.39	16.12 ± 5.08	15.29 ± 2.63	61.80 ± 18.46	62.83 ± 23.83	39.80 ± 11.07	41.96 ± 14.18
Post	35.54 ± 10.99	37.59 ± 9.443	17.91 ± 5.06	17.19 ± 3.04	61.13 ± 18.05	60.05 ± 23.00	40.76 ± 9.876	41.72 ± 13.71
Follow	34.86 ± 15.69	36.81 ± 11.75	17.78 ± 5.04	17.40 ± 2.63	61.08 ± 17.69	62.79 ± 22.03	41.53 ± 10.80	44.77 ± 13.71
Time (f, *P*)	0.594, *0.555*		5.878, *0.010* *		1.001, *0.374*		2.330, *0.106*	
Group (f, *P*)	0.621, *0.437*		0.218, *0.644*		0.006, *0.938*		0.116, *0.735*	
Group x Time (f, *P*)	0.575, *0.566*		0.070, *0.890*		0.643, *0.529*		0.582, *0.562*	

	Hip Extension		**Hip Flexion**		**Hip Abduction**		**Hip Adduction**	
	EXP	***CON***	***EXP***	***CON***	***EXP***	***CON***	***EXP***	***CON***
Pre	65.42 ± 20.93	74.99 ± 26.89	34.38 ± 8.332	37.21 ± 10.48	36.9 ± 13.40	45.09 ± 19.31	23.82 ± 6.741	23.24 ± 8.910
Post	68.58 ± 20.87	70.12 ± 26.35	38.98 ± 10.29	33.75 ± 9.155	45.5 ± 18.77	46.16 ± 15.56	28.32 ± 8.914	20.54 ± 8.802
Follow	73.75 ± 23.73	71.39 ± 28.50	39.45 ± 11.13	33.69 ± 10.06	49.86 ± 20.25	47.62 ± 14.69	30.07 ± 12.17	21.91 ± 8.517
Time (f, *P*)	0.554, *0.579*		0.134, *0.875*		4.929, *0.017**		2.492, *0.093*	
Group (f, *P*)	0.132, *0.719*		0.747, *0.394*		0.141, *0.710*		3.273, *0.082*	
Group x Time (f, *P*)	1.840, *0.168*		4.824, *0.012**		2.331, *0.118*		7.265, *0.002**	

Note: CON= Control group; EXP = Experimental Group. *denotes statistical significance

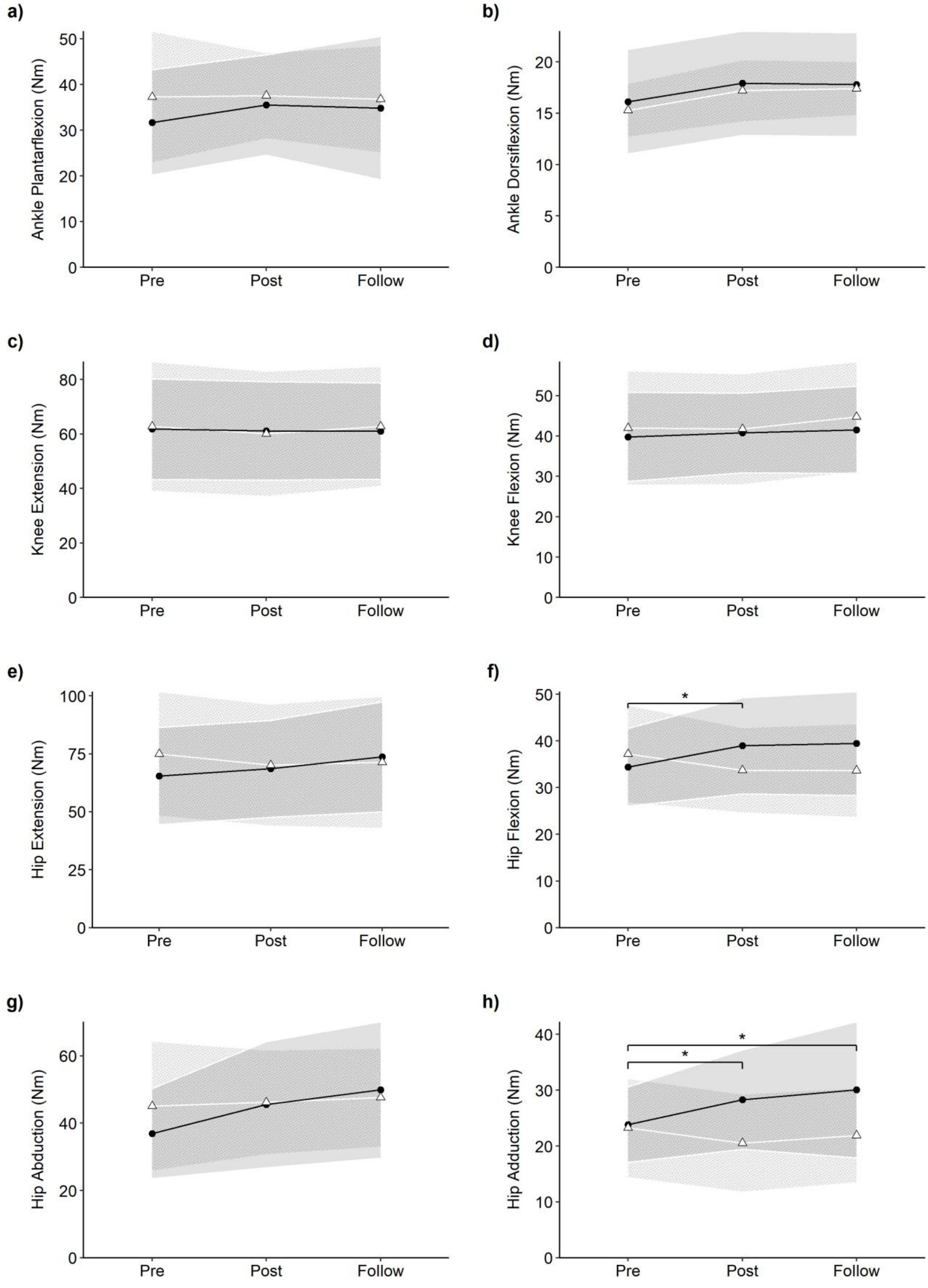

Figure 6-18 Pre-intervention, Post-intervention, and Follow-up Mean ± SD for absolute strength (a, ankle plantarflexion; b, ankle dorsiflexion; c, knee extension; d, knee flexion; e, hip extension; f, hip flexion; g, hip abduction; h, hip adduction) for the experimental (•) and control group (Δ). * on a dashed line denotes a significant change over time for the control group. * on a solid line denotes a significant change over time for the control group.

There was no significant difference in allometrically scaled ankle plantar flexion at baseline between the experimental group and control group ($p = 0.135$). There was no significant effect of time for allometrically scaled ankle plantar flexion. There was no significant effect of group for allometrically scaled ankle plantar flexion. There was no significant group by time effect for allometrically scaled ankle plantar flexion. Mean experimental group increases in allometrically scaled ankle plantarflexion did not meet the MDC threshold set out in Chapter 3.

There was no significant difference in allometrically scaled ankle dorsiflexion at baseline between the experimental group and control group ($p = 0.645$). There was a significant effect of time for allometrically scaled ankle dorsiflexion. *Post hoc* tests revealed a significant increase pre-intervention to post-intervention ($p = 0.001$, 95%CI [0.57, 0.252]), there was no significant change in allometrically scaled ankle dorsiflexion pre-intervention to follow-up ($p = 0.144$, 95%CI [-0.033, 0.314]) or post-intervention to follow-up ($p = 1.00$, 95%CI [-0.176, 0.149]). There was no significant effect of group for allometrically scaled ankle dorsiflexion. There was no significant group by time effect for allometrically scaled ankle dorsiflexion. Mean experimental group increases in allometrically scaled ankle dorsiflexion did not meet the MDC threshold set out in Chapter 3.

There was no significant difference in allometrically scaled knee extension at baseline between the experimental group and control group ($p = 0.796$). There was no significant effect of time for allometrically scaled knee extension. There was no significant effect of group for allometrically scaled knee extension. There was no significant group by time effect for allometrically scaled knee extension. Mean experimental group increases in allometrically scaled knee extension did not meet the MDC threshold set out in Chapter 3.

There was no significant difference in allometrically scaled knee flexion at baseline between the experimental group and control group ($p = 0.749$). There was no significant effect of time for allometrically scaled knee flexion. There was no significant effect of group for allometrically scaled knee flexion. There was no significant effect of group for allometrically scaled knee flexion. Mean experimental group increases in allometrically scaled knee flexion did not meet the MDC threshold set out in Chapter 4. Mean experimental group increases in allometrically scaled knee flexion did not meet the MDC threshold set out in Chapter 3.

There was no significant difference in allometrically scaled hip extension at baseline between the experimental group and control group ($p = 0.353$). There was a significant effect of time for allometrically scaled hip extension. *Post hoc* tests revealed the control group to have no significant changes in allometrically scaled hip extension pre- to post-intervention ($Z = -1.433$, $p = 0.152$), pre-intervention to follow-up ($Z = -2.062$, $p = 0.039$), or post-intervention to follow-up ($Z = -0.664$, $p = 0.507$). *Post hoc* tests revealed the experimental group to have no significant changes in allometrically scaled hip extension pre- to post-intervention ($Z = -0.588$, $p = 0.557$), pre-intervention to follow-up ($Z = -1.154$, $p = 0.248$), or post-intervention to follow-up ($Z = -0.544$, $p = 0.586$). There were no significant differences between groups post-intervention ($p = 0.089$, 95% CI [-0.149, 1.962]) and follow-up ($p = 0.046$, 95%CI [0.021, 2.011]). Mean experimental group increases in allometrically scaled hip extension did not meet the MDC threshold set out in Chapter 3.

There was no significant difference in allometrically scaled hip flexion at baseline between the experimental group and control group ($p = 0.477$). There was no significant effect of time for allometrically scaled hip flexion.

There was no significant effect of group for allometrically scaled hip flexion. There was a significant group by time effect for allometrically scaled hip flexion. *Post hoc* tests revealed the control group to have no significant changes in allometrically scaled hip flexion pre- to post-intervention (p = 0.102, 95%CI [-1.254, 0.083]), pre-intervention to follow-up (p = 0.225, 95%CI [-1.740, 0.275]), or post-intervention to follow-up (p = 1.00, 95%CI [-1.163, 0.869]). The experimental group had a significant increase in allometrically scaled hip flexion pre- to post-intervention (p = 0.016, 95%CI [0.107, 1.244]), but no significant changes post-intervention to follow-up (p = 1.00, 95%CI [-0.901, 0.825]) or pre-intervention to follow-up (p = 0.205, 95%CI [-0.219, 1.494]). Comparisons between groups at time points revealed no significant differences between groups at post-intervention (p = 0.089, 95%CI [-0.0149, 1.962]) and follow-up (p = 0.046, 95%CI [0.21, 2.011]). Mean experimental group increases in allometrically scaled hip flexion did not meet the MDC threshold set out in Chapter 3.

There was no significant difference in allometrically scaled hip abduction at baseline between the experimental group and control group (p = 0.189). There was a significant effect of time for allometrically scaled hip abduction. *Post hoc* tests revealed no significant differences between pre- to post-intervention (p = 0.208, 95%CI [-0.060, 0.404]), pre-intervention to follow-up (p = 0.041, 95%CI [0.008, 0.473]), or post-intervention to follow-up (p = 1.00, 95%CI [-0.115, 0.252]). There was no significant effect of group for allometrically scaled hip abduction. There was no significant group by time effect for allometrically scaled hip abduction. Mean experimental group increases in allometrically scaled hip abduction did not meet the MDC threshold set out in Chapter 3.

There was no significant difference in allometrically scaled hip adduction at baseline between the experimental group and control group (p = 0.554). There was no significant effect of time for allometrically scaled hip adduction. There was a significant effect of group for allometrically scaled hip adduction. *Post hoc* tests revealed the experimental group to have greater allometrically scaled hip adduction (p = 0.005, 95%CI [0.054, 0.273]). There was a significant group by time effect for allometrically scaled hip adduction. *Post hoc* tests revealed the control group to have no significant changes in allometrically scaled hip adduction pre- to post-intervention (p = 0.062, 95%CI [-0.161, 0.043]), pre-intervention to follow-up (p = 0.403, 95%CI [-0.175, 0.43]), or post-intervention to follow-up (p = 1.00, 95%CI [-0.115, 0.141]). The experimental group had significant increases in allometrically scaled hip adduction pre- to post-intervention (p = 0.002, 95%CI [0.040, 0.192]), pre-intervention to follow-up (p = 0.011, 95%CI [0.025, 0.228]), but no significant increase post-intervention to follow-up (p = 1.00, 95%CI [-0.109, 0.130]). Comparisons between groups at time points revealed the experimental group to be significantly stronger than the control group at post-intervention (p < 0.001, 95%CI [0.117, 0.341]) and follow-up (p = 0.006, 95%CI [0.072, 0.381]). Mean experimental group increases in allometrically scaled hip adduction did not meet the MDC threshold set out in Chapter 3.

Table 6-9 Pre-intervention, Post-intervention, and Follow-up Mean ± SD of allometrically scaled strength and main ANOVA effects of time and group for the experimental and control group, and non-parametric results.

	Ankle Plantarflexion (Nm/kg^b)		**Ankle Dorsiflexion (Nm/kg^b)**		**Knee Extension (Nm/kg^b)**		**Knee Flexion (Nm/kg^b)**	
	EXP	***CON***	***EXP***	***CON***	***EXP***	***CON***	***EXP***	***CON***
Pre	1.34 ± 0.35	1.54 ± 0.37	1.45 ± 0.26	1.41 ± 0.25	2.24 ± 0.54	2.19 ± 0.54	1.60 ± 0.31	1.63 ± 0.29
Post	1.54 ± 0.46	1.56 ± 0.32	1.62 ± 0.30	1.54 ± 0.20	2.22 ± 0.52	2.04 ± 0.48	1.66 ± 0.33	1.59 ± 0.27
Follow	1.45 ± 0.58	1.49 ± 0.39	1.59 ± 0.35	1.55 ± 0.27	2.15 ± 0.43	2.08 ± 0.46	1.63 ± 0.3	1.66 ± 0.23
Time (f, *P*)	1.028, *0.350*		5.114, *0.017**		2.461, *0.094*		0.287, *0.751*	
Group (f, *P*)	0.714, *0.494*		0.522, *0.476*		0.338*, 0.565*		0.002, *0.964*	
Group x Time (f, *P*)	0.714, *0.462*		0.052, *0.909*		1.101, *0.339*		0.752, *0.476*	

	Hip Extension (Nm/kg^b)		**Hip Flexion (Nm/kg^b)**		**Hip Abduction (Nm/kg^b)**		**Hip Adduction (Nm/kg^b)**	
	EXP	***CON***	***EXP***	***CON***	***EXP***	***CON***	***EXP***	***CON***
Pre	2.74 ± 0.82	3.01 ± 0.63	5.52 ± 1.34	5.88 ± 1.36	1.48 ± 0.51	1.72 ± 0.41	0.59 ± 0.15	0.56 ± 0.15
Post	2.86 ± 0.83	2.74 ± 0.63	6.20 ± 1.46	5.29 ± 1.35	1.78 ± 0.59	1.76 ± 0.44	0.71 ± 0.13	0.48 ± 0.16
Follow	2.95 ± 0.66	2.69 ± 0.62	6.16 ± 1.40	5.15 ± 1.24	1.91 ± 0.55	1.76 ± 0.37	0.72 ± 0.24	0.49 ± 0.13
	Ŧ							
Time (f, *P*)	EXP = 9.33, *0.009** CON = 9.3, *0.010**		0.77, *0.893*		4.255*, 0.019**		0.559*, 0.540*	
Group (f, *P*)	0.031, *0.862*		1.570, *0.220*		0.018, *0.895*		9.361, *0.005**	
Group x Time (f, *P*)			5.230, *0.013**		2.720, *0.075*		7.489*, 0.003**	

Note: CON= Control group; EXP = Experimental Group, * denotes statistical significant

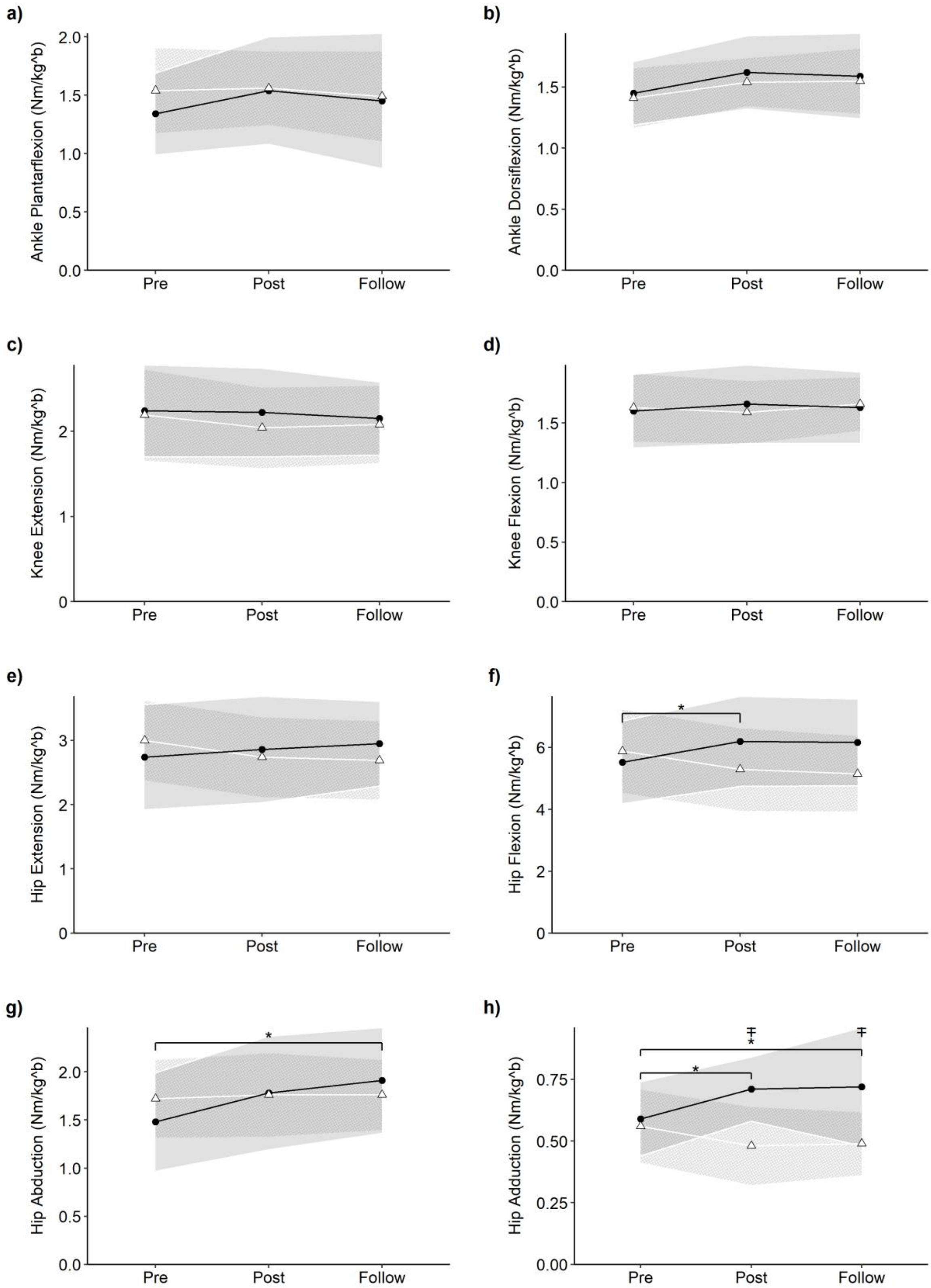

Figure 6-19 Pre-intervention, Post-intervention, and Follow-up Mean ± SD for allometrically scaled strength (a, ankle plantarflexion; b, ankle dorsiflexion; c, knee extension; d, knee flexion; e, hip extension; f, hip flexion; g, hip abduction; h, hip adduction) for the experimental group. * on a dashed line denotes a significant change over time for the control group. * on a solid line denotes a significant change over time for the control group, Ŧ denotes a significant difference between groups at time point.

6.4.4.3 Temporal spatial parameters of gait.

There was no significant difference in double stance time at baseline between the experimental group and control group (*p* = 0.946). There was no significant effect of time for double stance time. There was no significant effect of group for double stance time. There was no significant group by time effect for double stance time (Table 6-10; Figure 6-20).

There was no significant difference in stance phase time at baseline between the experimental group and control group (*p* = 0.679). There was a significant effect of time for stance phase time (Table 6-10; Figure 6-20). *Post hoc* tests revealed no significant difference in stance phase time between pre- to post-intervention (*p* = 0.092, 95%CI [-0.002, 0.033]), pre-intervention to follow-up (*p* = 0.079, 95%CI [-0.002, 0.53]), or post-intervention to follow-up (*p* = 0.777, 95%CI [-0.012, 0.031]). There was no significant effect of group for stance phase time. There was no significant group by time effect for stance phase time.

There was no significant difference in stride length/leg length at baseline between the experimental group and control group (*p* = 0.507). There was no significant effect of time for stride length/leg length (Table 6-10; Figure 6-20). There was no significant effect of group for stride length/leg length. There was no significant group by time effect for stride length/leg length.

There was no significant difference in gait velocity at baseline between the experimental group and control group (*p* = 0.536). There was no significant effect of time for gait velocity (Table 6-10; Figure 6-20). There was no significant effect of group for stride length/leg length. There was no significant group by time effect for gait velocity.

There was no significant difference in step width at baseline between the experimental group and control group (*p* = 0.257). There was no significant effect of time for step width (Table 6-10; Figure 6-20). There was no significant effect of group for step width. There was no significant group by time effect for step width.

6.4.4.4 Mediolateral centre of mass during the single stance phase of gait

There was no significant difference in mediolateral CoM mean velocity at baseline between the experimental group and control group (*p* = 0.618). There was a significant effect of time for mediolateral CoM velocity. *Post hoc* tests revealed no significant difference in mediolateral CoM velocity between pre- to post-intervention (*p* = 1.00, 95%CI [-0.002, 0.003]), pre-intervention to follow-up (*p* = 0.039, 95%CI [-0.004, 0.000]), or post-intervention to follow-up (*p* = 0.205, 95%CI [-0.004, 0.001]). There was no significant effect of group for mediolateral CoM mean velocity. There was no significant group by time effect for mediolateral CoM mean velocity (Table 6-11; Figure 6-21).

There was no significant difference in mediolateral CoM SD velocity at baseline between the experimental group and control group (*p* = 0.991). There was a significant effect of time for mediolateral CoM velocity. *Post hoc* tests revealed no significant difference in mediolateral CoM SD velocity between pre- to post-intervention (*p* = 0.390, 95%CI [-0.001, 0.003]), or post-intervention to follow-up (*p* = 0.233, 95%CI [-0.003, 0.001]). There was a significant decrease in mediolateral CoM SD velocity from pre-intervention to follow-up (*p* = 0.004, 95%CI [-0.004, -0.001]). There was no significant effect of group for mediolateral CoM SD velocity. There was no significant group by time effect for mediolateral CoM SD velocity (Table 6-11; Figure 6-21).

There was no significant difference in mediolateral CoM maximal displacement at baseline between the experimental group and control group ($p = 0.382$). There was no significant effect of time for mediolateral CoM maximal displacement. There was no significant effect of group for mediolateral CoM maximal displacement. There was no significant group by time effect for mediolateral CoM maximal displacement (Table 6-11; Figure 6-21).

Table 6-10 Pre-intervention, Post-intervention, and Follow-up Mean ± SD of temporal spatial parameters and main ANOVA effects of time and group for the experimental and control group.

	Double Support Time (s)		**Stance Phase Time (s)**		**Stride Length / Leg Length (m)**		**Gait Velocity (m/s)**		**Step Width (m)**	
	EXP	***CON***	***EXP***	***CON***	***EXP***	***CON***	***EXP***	***CON***	***EXP***	***CON***
Pre	0.10 ± 0.03	0.10 ± 0.03	0.57 ± 0.07	0.56 ± 0.07	1.70 ± 0.38	1.80 ± 0.38	1.22 ± 0.29	1.29 ± 0.30	0.11 ± 0.02	0.12 ± 0.03
Post	0.10 ± 0.03	0.11 ± 0.03	0.57 ± 0.07	0.59 ± 0.08	1.64 ± 0.43	1.81 ± 0.44	1.18 ± 0.36	1.27 ± 0.36	0.11 ± 0.02	0.12 ± 0.04
Follow	0.11 ± 0.02	0.12 ± 0.03	0.59 ± 0.07	0.58 ± 0.07	1.79 ± 0.29	1.68 ± 0.33	1.26 ± 0.22	1.19 ± 0.22	0.11 ± 0.03	0.13 ± 0.04
Time (f, *P*)	6.820, *0.002 **		2.397, *0.101*		0.029, *0.971*		0.102, *0.903*		0.323, *0.726*	
Group (f, *P*)	0.518, *0.479*		0.00, *0.986*		0.309, *0.583*		0.142, *0.710*		1.927, *0.178*	
Group x Time (f, *P*)	1.485, *0.236*		2.020, *0.143*		1.178, *0.316*		0.805, *0.453*		0.347, *0.708*	

Note: EXP = experimental group, CON = Control group, * denotes statistical significance

Table 6-11 Pre-intervention, Post-intervention, and Follow-up Mean ± SD of the centre of mass using single stance and main ANOVA effects of time and group for the experimental and control group.

	Mean M/L CoM Velocity (m/s)		**SD M/L CoM Velocity (m/s)**		**Maximal M/L CoM Displacement (m)**	
	EXP	***CON***	***EXP***	***CON***	***EXP***	***CON***
Pre	0.015 ± 0.004	0.014 ± 0.002	0.010 ± 0.003	0.010 ± 0.003	0.274 ± 0.108	0.234 ± 0.082
Post	0.015 ± 0.005	0.012 ± 0.005	0.010 ± 0.004	0.008 ± 0.005	0.265 ± 0.102	0.250 ± 0.200
Follow	0.013 ± 0.005	0.011 ± 0.004	0.008 ± 0.003	0.007 ± 0.003	0.245 ± 0.112	0.204 ± 0.174
Time (f, *P*)	3.925, *0.028 **		6.377, *0.004**		2.652, *0.084*	
Group (f, *P*)	1.087, *0.310*		0.533, *0.474*		1.478, *0.239*	
Group x Time (f, *P*)	0.598, *0.555*		0.833, *0.443*		0.318, *0.730*	

Note: EXP = experimental group, CoM = Centre of mass, CON = Control group, M/L = mediolateral, * denotes statistical significance

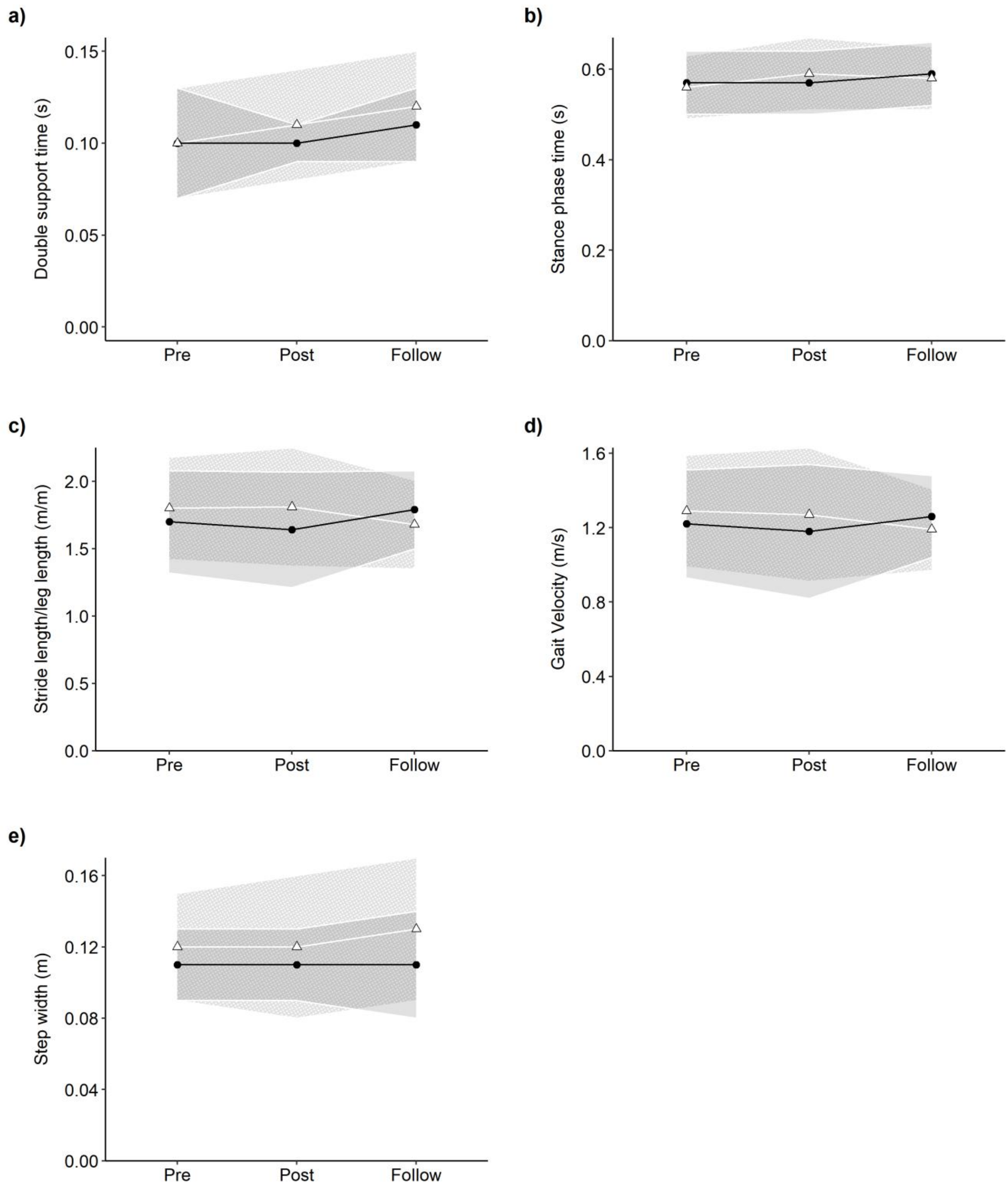

Figure 6-20 Pre-intervention, Post-intervention, and Follow-up Mean ± SD for temporal-spatial parameters of gait (a, double support time; b, stance phase time; c, stride length/leg length; d, gait velocity; e, step width) for the experimental group. * on a dashed line denotes a significant change over time for the control group. * on a solid line denotes a significant change over time for the control group.

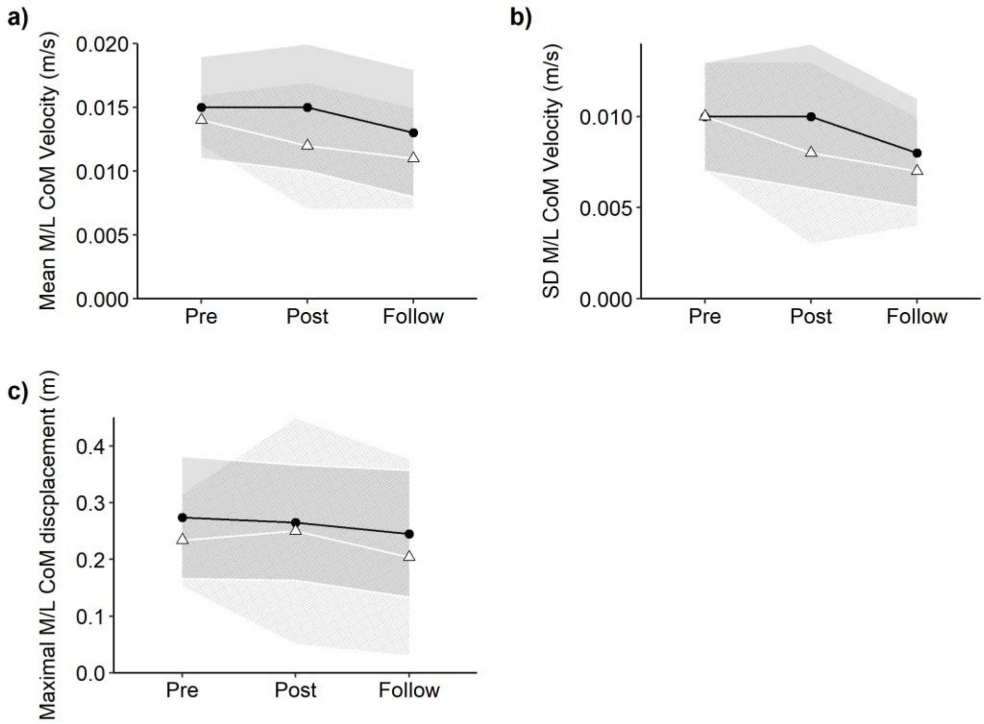

Figure 6-21 Pre-intervention, Post-intervention, and Follow-up Mean ± SD for allometrically scaled strength (a, mean mediolateral centre of mass velocity; b, standard deviation of mediolateral centre of mass velocity; c, maximal mediolateral centre of mass displacement) for the experimental group. * on a dashed line denotes a significant change over time for the control group. * on a solid line denotes a significant change over time for the control group.

6.4.4.5 3D Foot motion during stance

No effect of time was found in the shank to calcaneus range or midfoot to metatarsal angle in either the control or the experimental group (Figure 6-22 and 6-24). In calcareous to midfoot angle, there was an effect of time for the experimental group in the front plane (p=0.035; Figure 6-23). *Post hoc* analysis revealed the experimental group to be significantly less adducted (eversion) during 94-95% of stance at follow-up compared to pre-intervention (p= 0.006). The mean difference between pre and follow-up (5.08-5.15°) does meet the MDC thresholds set out in Section 3.4.

6.4.4.6 3D lower limb joint kinematics

No effect of time was found in either the control group or experimental group for any lower limb joint angle (Figures 6-26, 6-26, and 6-27).

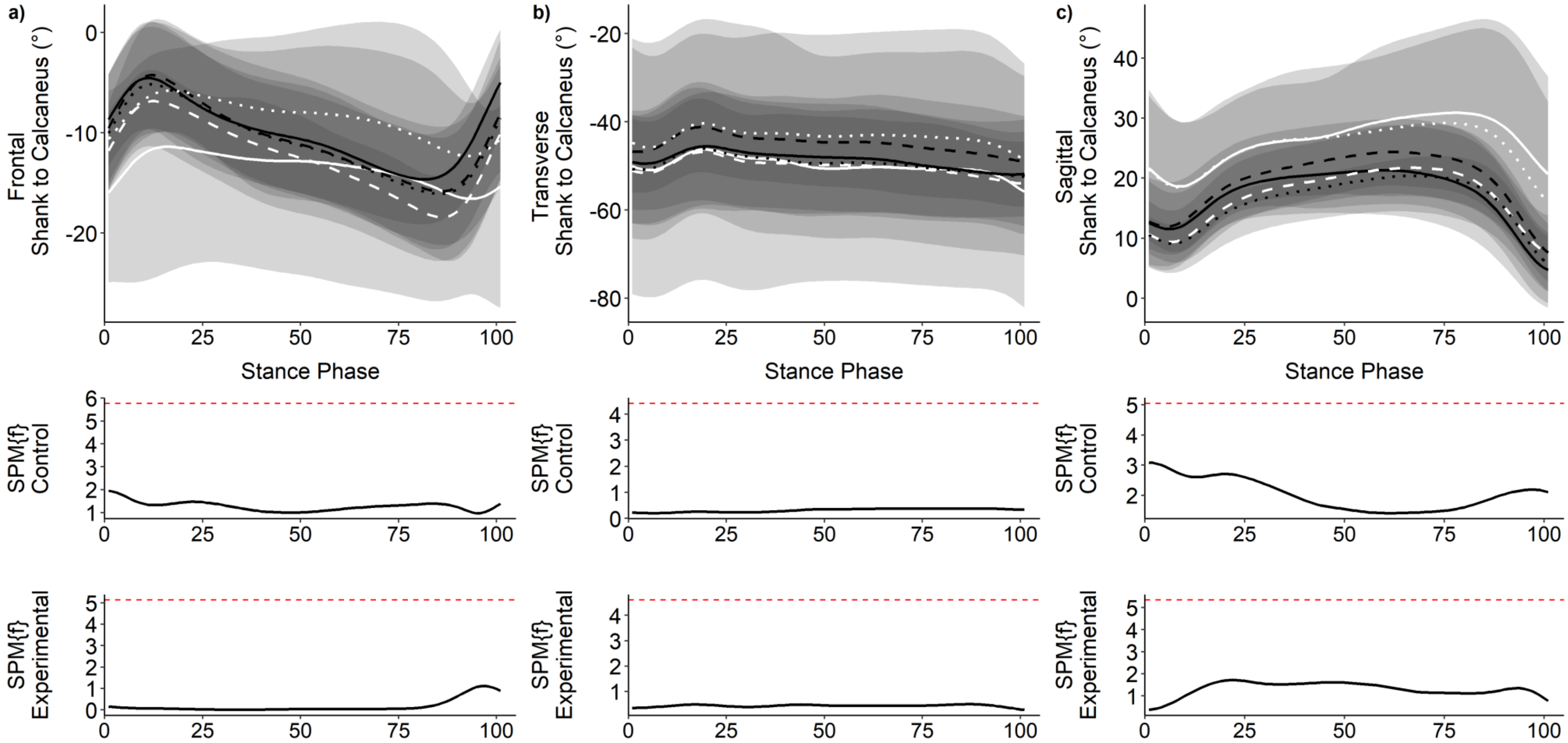

Figure 6-22 Shank to calcaneus angle during stance phase for the experimental and control group, pre-, post-intervention and follow-up and statistical parametric mapping (SPM) results effect of time for A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line, red dashed line = SPM significance threshold

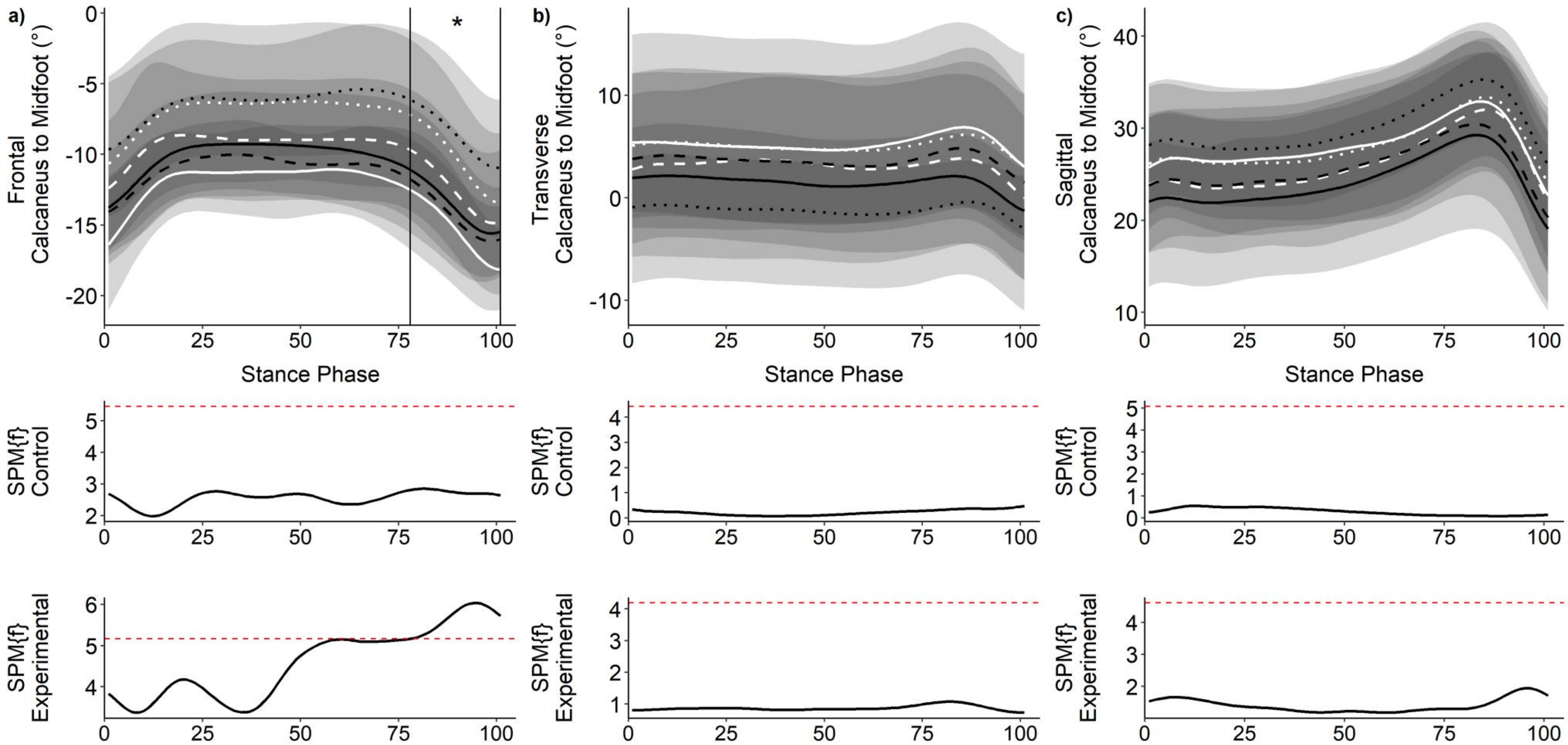

Figure 6-23 Calcaneus to midfoot angle during stance phase for the experimental and control group, pre-, post-intervention and follow-up and statistical parametric mapping (SPM) results effect of time for A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line, red dashed line = SPM significance threshold.

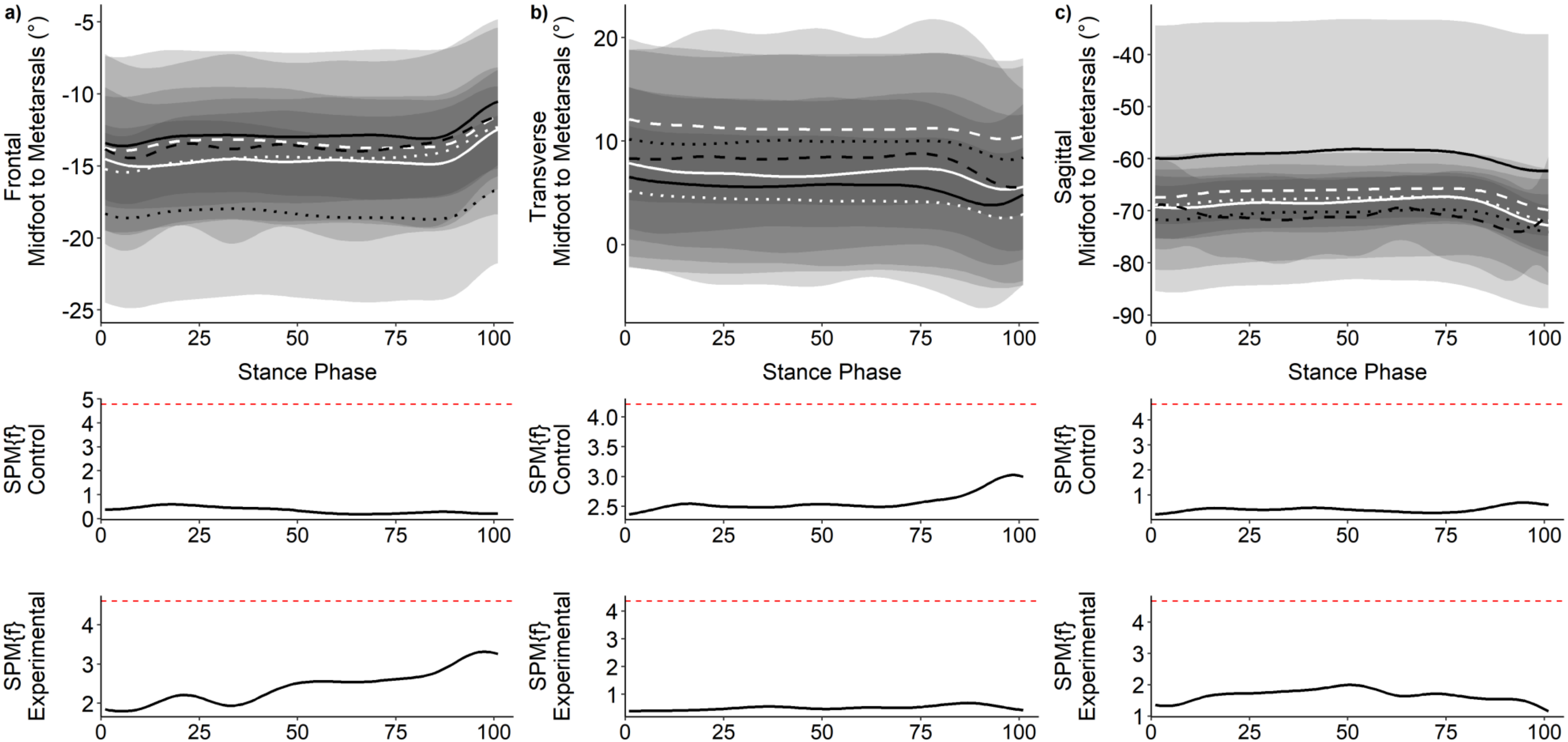

Figure 6-24 Midfoot to metatarsal angle during stance phase for the experimental and control group, pre-, post-intervention and follow-up and statistical parametric mapping (SPM) results effect of time for A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line, red dashed line = SPM significance threshold.

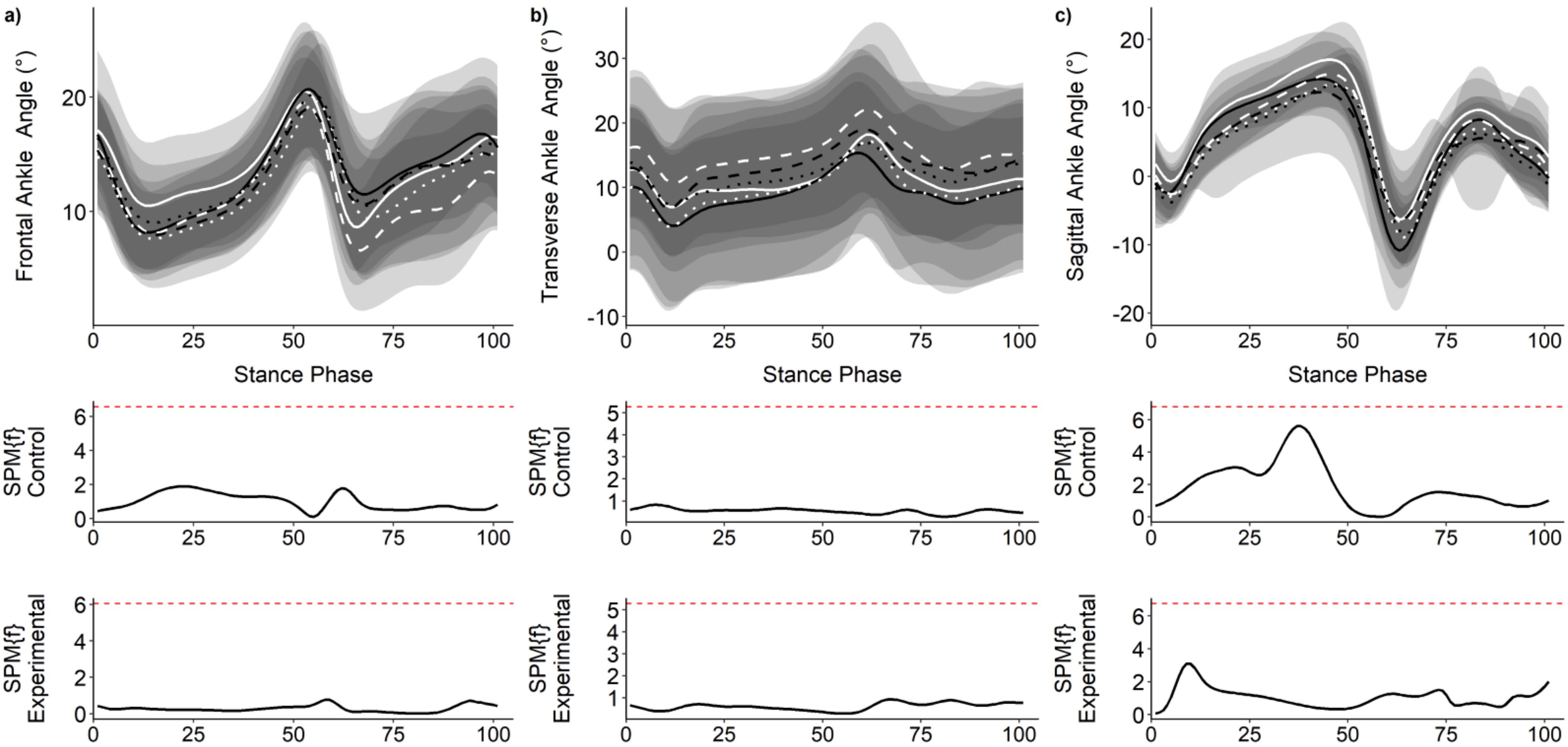

Figure 6-25 Ankle angle during stance phase for the experimental and control group, pre-, post-intervention and follow-up and statistical parametric mapping (SPM) results effect of time for A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line, red dashed line = SPM significance threshold.

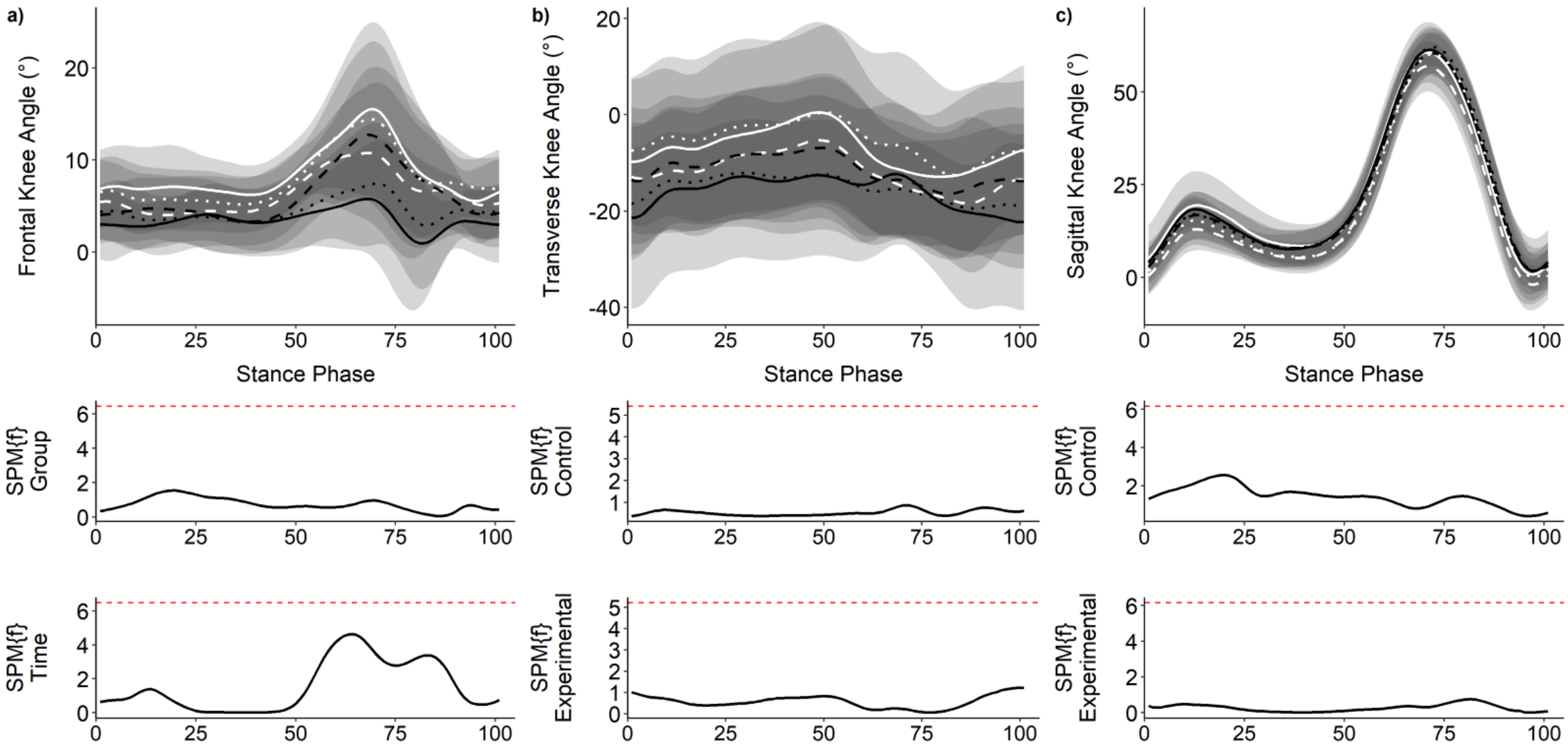

Figure 6-26 Knee angle during stance phase for the experimental and control group, pre-, post-intervention and follow-up and statistical parametric mapping (SPM) results effect of time for A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line, red dashed line = SPM significance threshold.

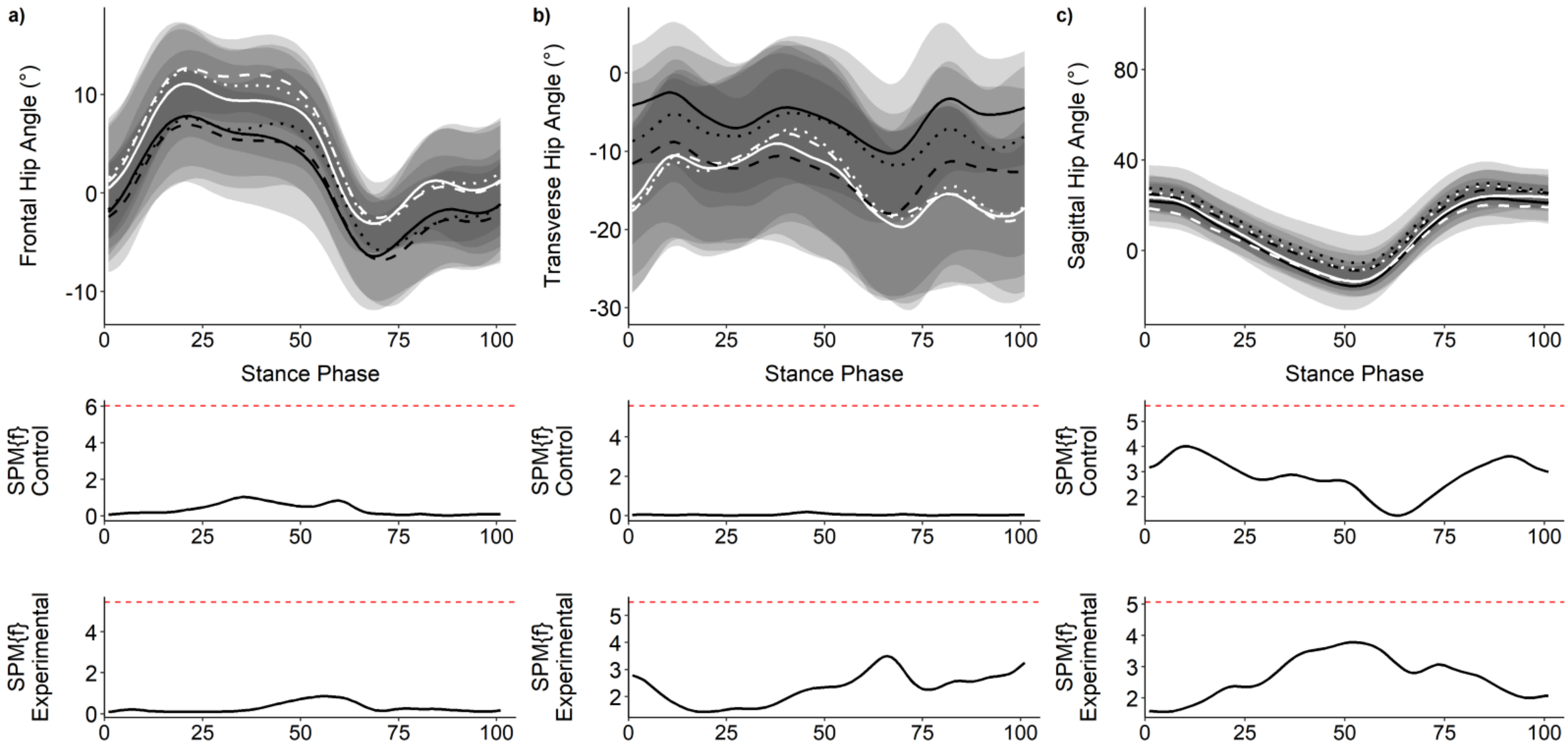

Figure 6-27 Knee angle during stance phase for the experimental and control group, pre-, post-intervention and follow-up and statistical parametric mapping (SPM) results effect of time for A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line, red dashed line = SPM significance threshold.

6.4.4.7 3D lower limb joint kinematics

There was no effect of time found in either the control group or the experiential group for ankle and knee joint moments (Figure 6-28 and 6-29). A significant effect of time was found in the experimental group for a transverse hip moment 51-93% of the stance phase. *Post hoc* analysis revealed the experimental group to have greater internal hip rotation moment at follow-up compared to pre-intervention 57-81% of stance (Figure -30). The mean difference of the pre-intervention and follow-up waveforms at 57-81% of the stance phase (0.0212 to 0.0285) did not meet the MDC threshold (0.07) set out in Chapter 3. There was no effect of time found in either the control group or the experimental group for ankle, knee, and hip joint power (Figure 6-31, 6-32, 6-33).

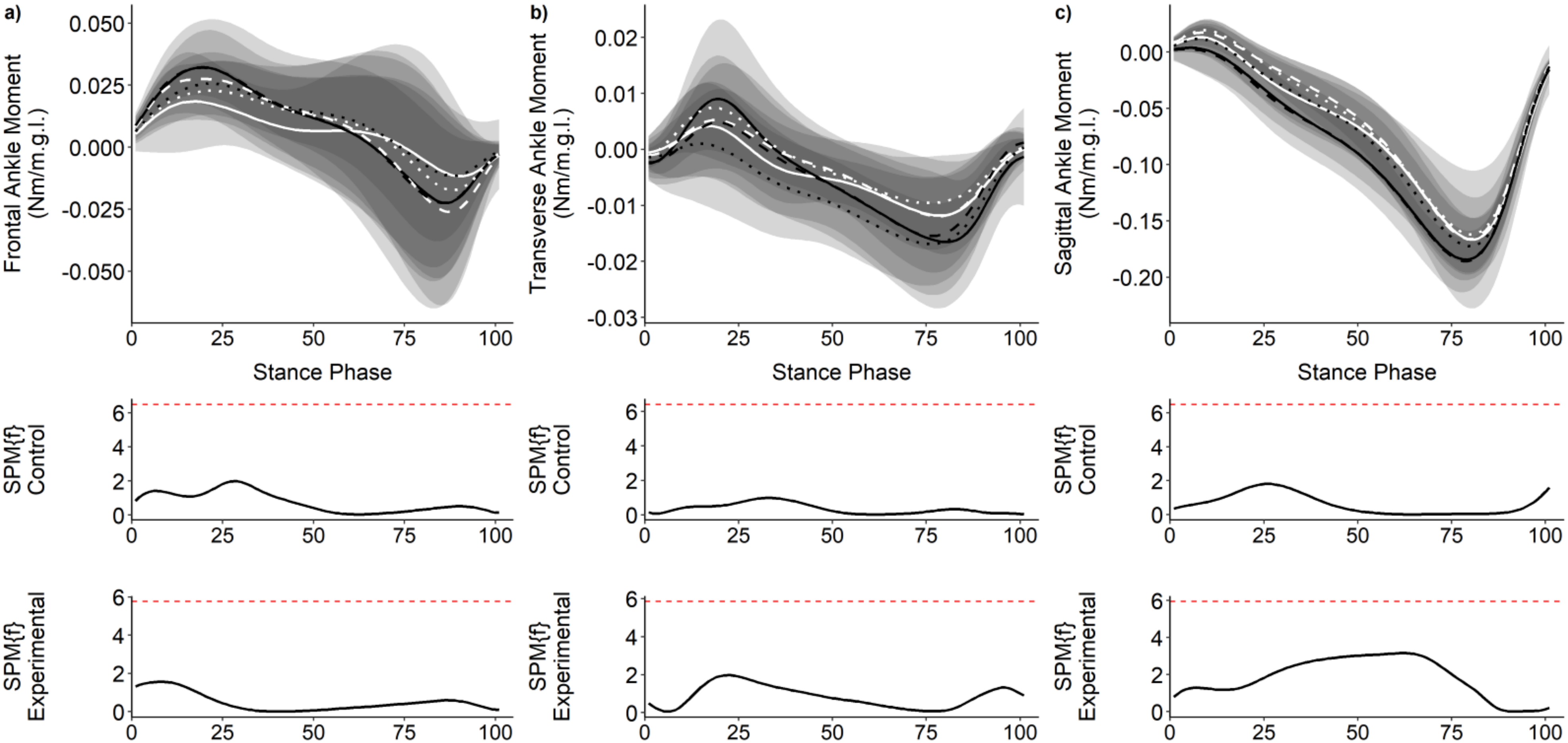

Figure 6-28 Ankle moment during stance phase for the experimental and control group, pre-, post-intervention and follow-up and statistical parametric mapping (SPM) results effect of time for A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line, red dashed line = SPM significance threshold.

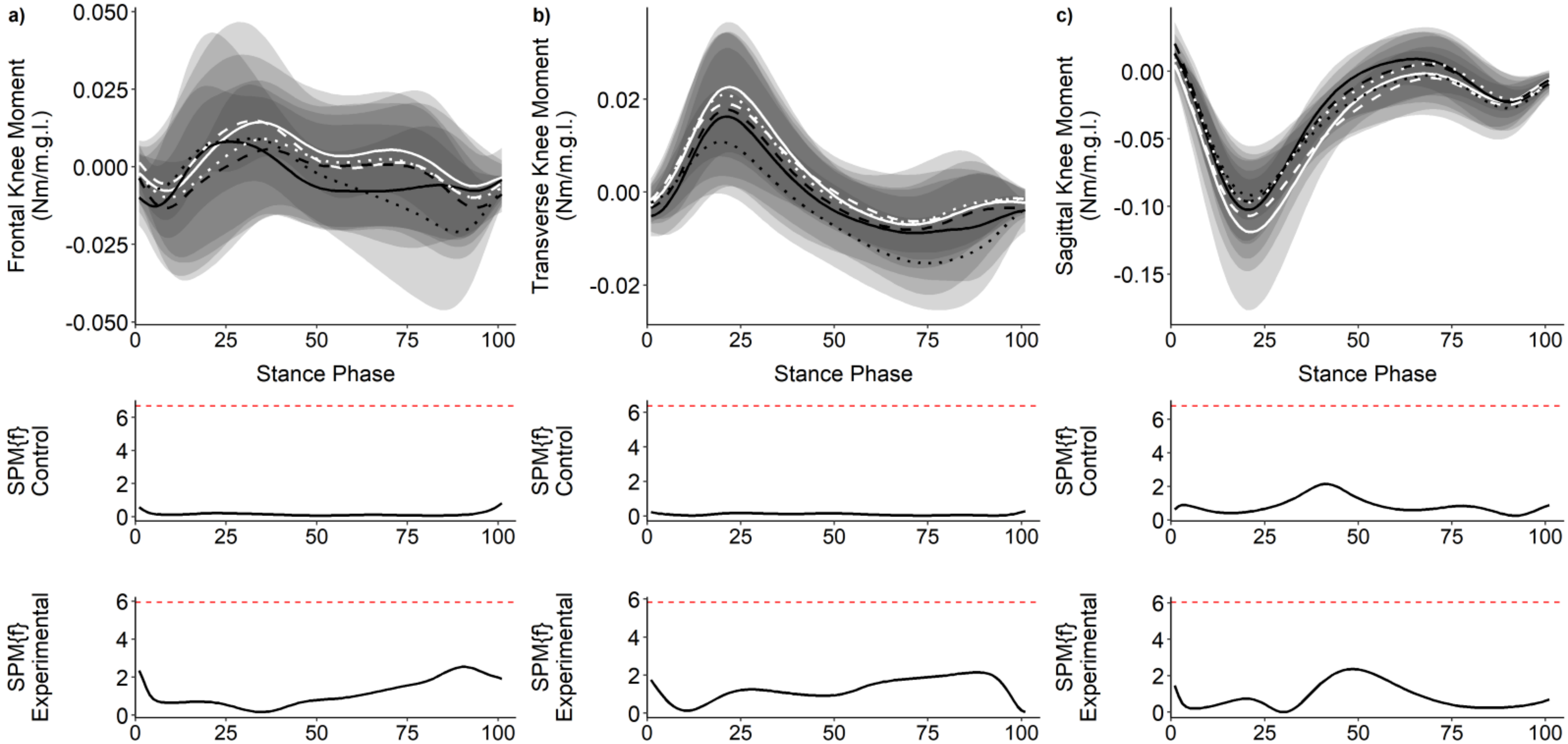

Figure 6-29 Knee moment during stance phase for the experimental and control group, pre-, post-intervention and follow-up and statistical parametric mapping (SPM) results effect of time for A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line, red dashed line = SPM significance threshold.

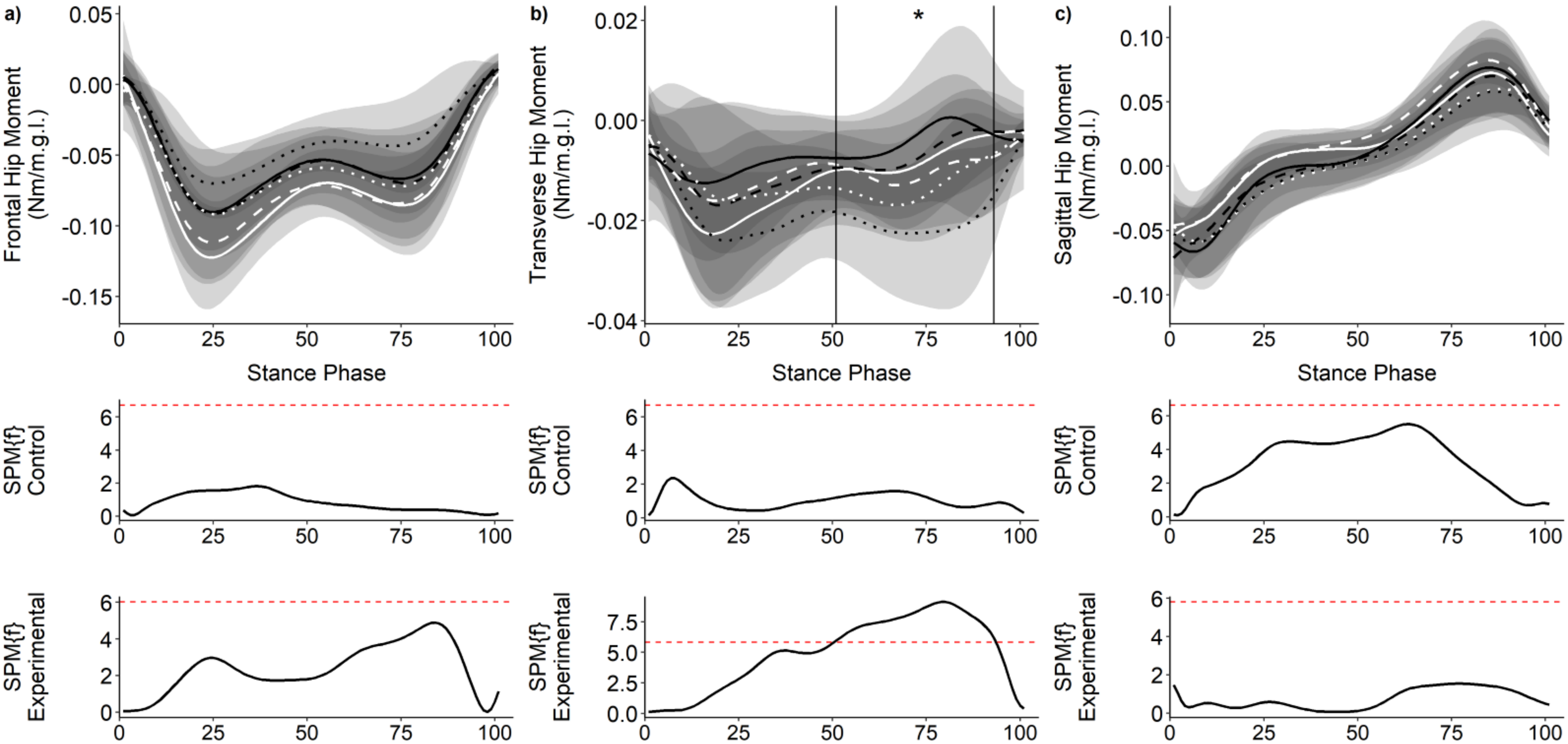

Figure 6-30 Hip moment during stance phase for the experimental and control group, pre-, post-intervention and follow-up and statistical parametric mapping (SPM) results effect of time for A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line, red dashed line = SPM significance threshold.

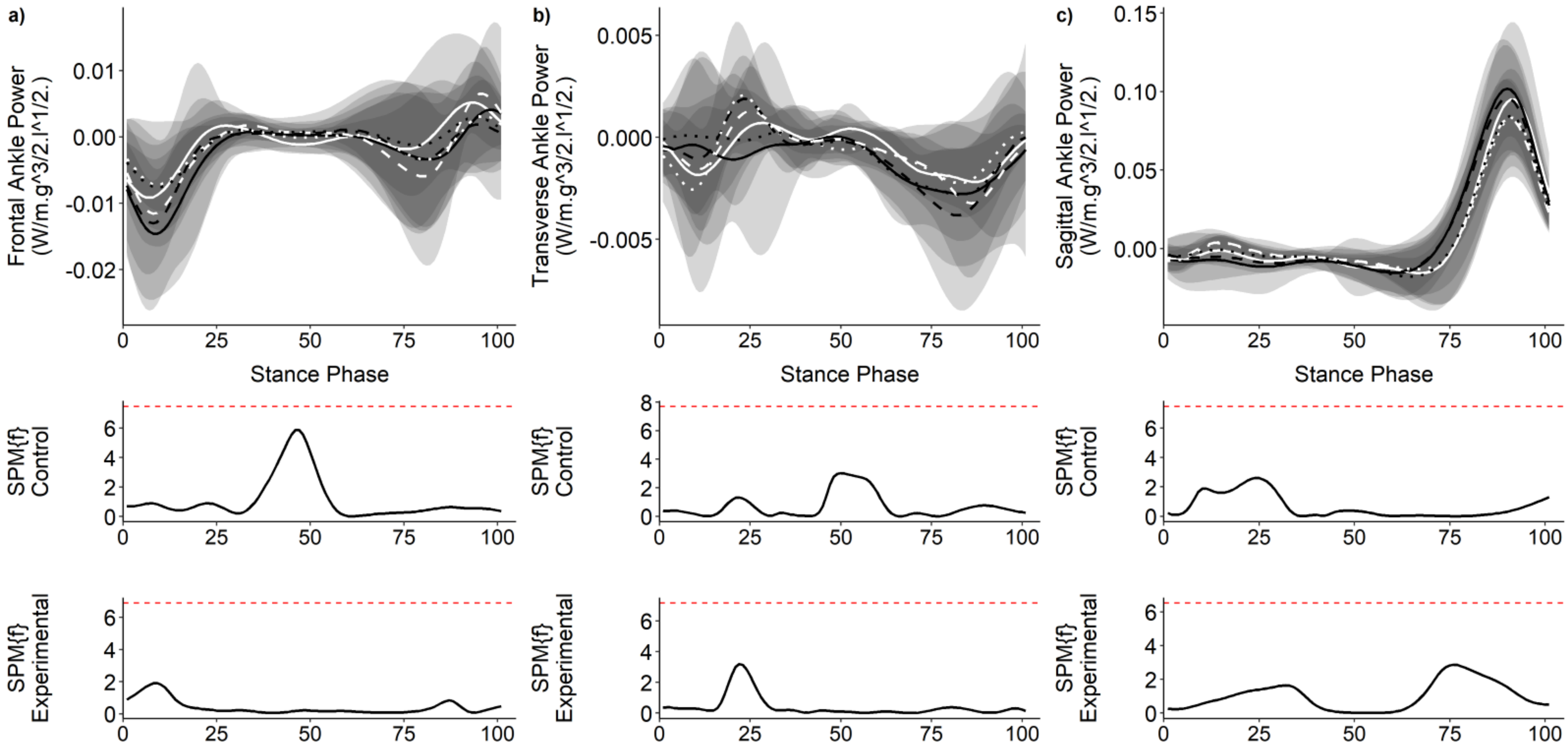

Figure 6-31 Ankle power during stance phase for the experimental and control group, pre-, post-intervention and follow-up and statistical parametric mapping (SPM) results effect of time for A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line, red dashed line = SPM significance threshold.

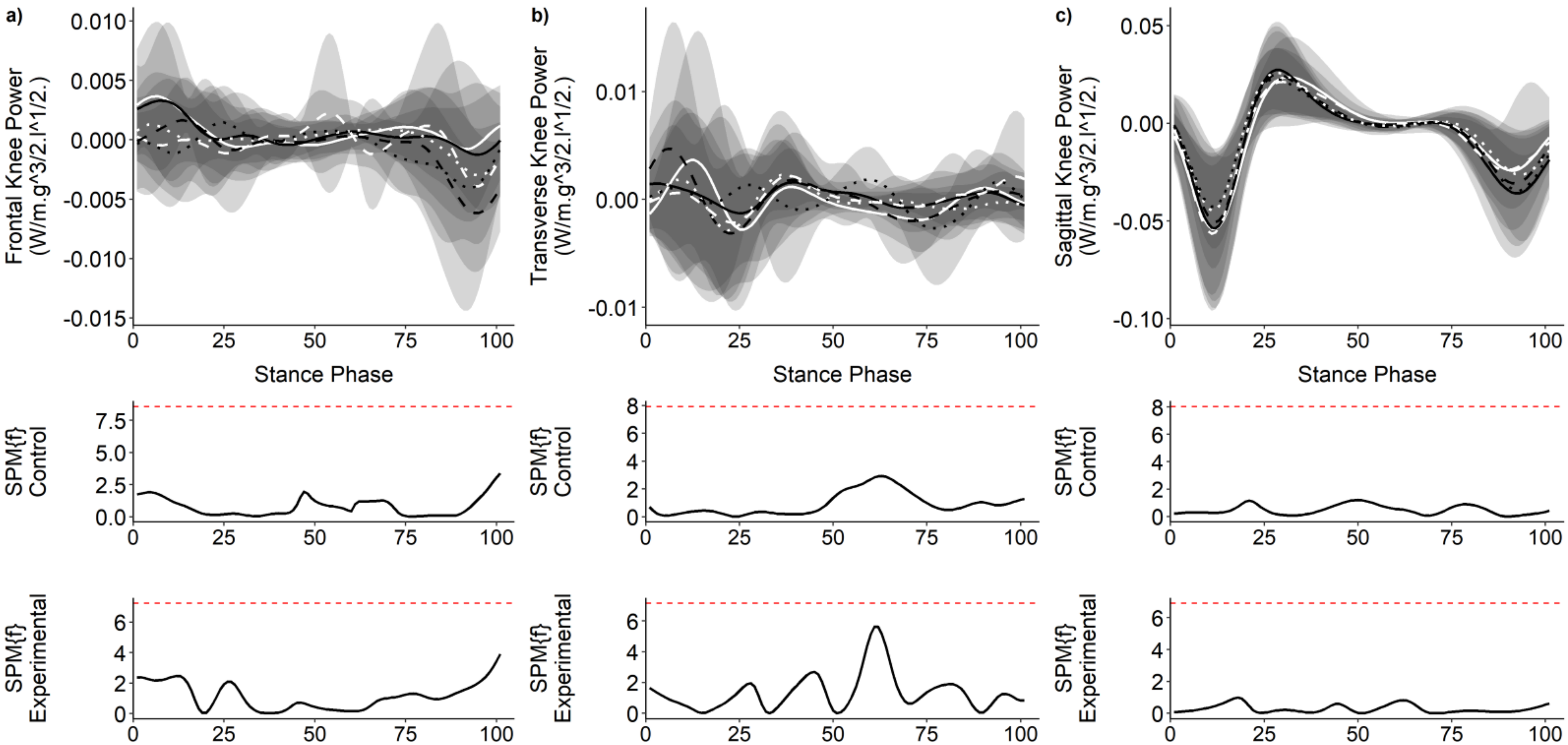

Figure 6-32 Knee power during stance phase for the experimental and control group, pre-, post-intervention and follow-up and statistical parametric mapping (SPM) results effect of time for A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line, red dashed line = SPM significance threshold.

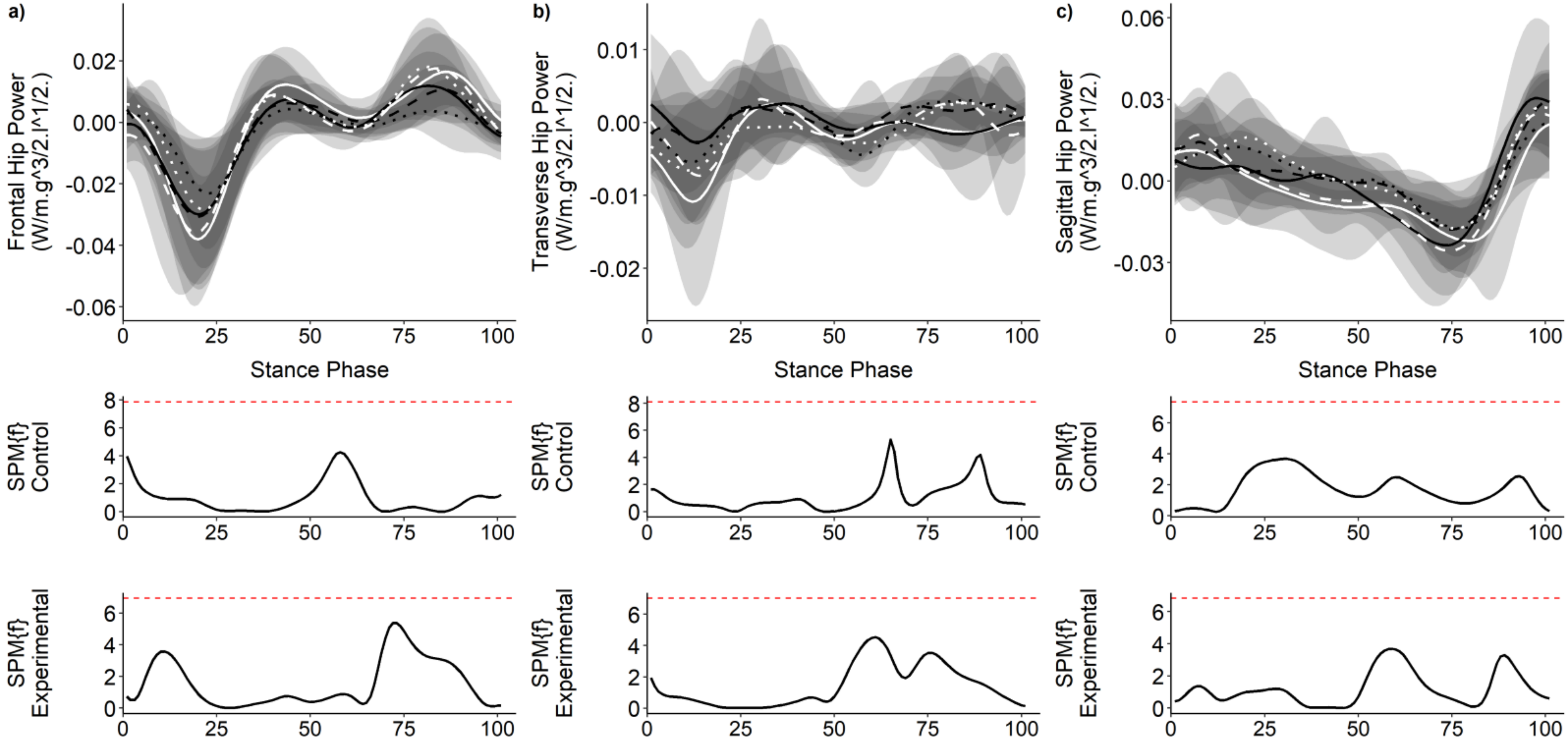

Figure 6-33 Hip power during stance phase for the experimental and control group, pre-, post-intervention and follow-up and statistical parametric mapping (SPM) results effect of time for A) Frontal plane, B) Transverse plane and C) Sagittal plane. Experimental group = Black line, Control group = White line, Pre-intervention = solid line, post-intervention = dashed line, follow-up = dotted line, red dashed line = SPM significance threshold.

6.5 Discussion

The aim of this study was to determine the effectiveness of a co-produced school-based intervention designed to improve postural stability and muscular strength, clinical measures of physical function, 3D gait and physical well-being in children with OWB. Intervention session MVPA was high, and there were positive associations between competency, enjoyment and session PA. There were several beneficial findings as a result of the exercise intervention. There was no increase in body mass in the experimental group during the intervention period, whilst the control group increased. The experimental group decreased BMI Z-score over the duration of the study, while the control group remained the same. The experimental group improved performance in STS and TUG tests whilst control groups had no change or had performance decline over the study duration. The experimental group had significant increases in absolute and allometrically scaled hip flexion and hip adduction, whilst no change was seen in the control group. Mean experimental group increases were also found in absolute hip extension and hip abduction despite no statistical significance. Finally, the experimental group exhibited less midfoot eversion after the exercise intervention.

6.5.1 Intervention attendance, intervention activity, basic psychological needs and enjoyment

The current study's mean attendance was 72.8%, which is similar to the 73% stated in the pilot study. However, reasons for non-attendance differed, with no participants choosing not to attend this chapter's intervention, while 59.18% of absences in the pilot study were due to participants choosing not to attend. This is likely due to the move away from playtimes, as well as other adjustments. Sickness was slightly greater in the current study (26% vs. 20% in the pilot). The intervention took place at the same time of year (January to June). However, it is worth noting that the pilot intervention occurred prior to the 2020 COVID-19 pandemic, while the current study took place between 2022 and 2024, with the 2022 cohorts still impacted by the pandemic. Moreover, total attendance in the current study was affected by a series of teacher strikes in 2023, which resulted in school closures. Additionally, 22.77% of sessions were missed by participants when the hosting school was unable to provide space for intervention sessions. Typically, physical education (PE) is more likely to be cancelled than other school subjects, often, as was the case in the current study, due to spaces being used for exams, school productions, or assemblies (Hardman, 2008). Whilst PA-type activities, including PE, may be valued, they are often not prioritised (Cruickshank et al., 2023). Nevertheless, despite these setbacks, total attendance did not drop far below previous work. All intervention sessions that children were able to attend were attended by choice, which may indicate a positive perception of the intervention sessions.

On average, 52.4% of session time was spent in MVPA. This is a greater proportion of time spent in MVPA than reported for PE classes (<37.4%) in the same age group (Fairclough & Stratton, 2006). There may be several reasons for this, including the guided play approach, where children were able to choose activities they wanted to do and, therefore, engaged in them more. Additionally, primary PE classes that are centred on sports skills often require drilling these skills, which frequently necessitates children waiting in line for their turn (Powell et al., 2019). The current intervention may have promoted greater MVPA through its availability and free choice over activities (therefore promoting activity as participants were engaged in activities they chose to do) and play-type activity that may differ from a more structured and sports skill drilling environment.

When examining counts per minute (with more counts per minute interpreted as more activity and greater movement intensity), age, and FM (%) were negatively associated with counts per minute. Participants who were older and heavier demonstrated less intense activity. This may be an important factor for the future development of primary school-age children, who may need to be divided into smaller age groups to better meet their specific needs.

With regard to enjoyment and need satisfaction, greater participant-reported enjoyment was significantly associated with greater total activity. Additionally, greater feelings of competency were associated with less time spent in sedentary activity. The significant relationships between intervention session PA levels, enjoyment, and BPN satisfaction provide further support for creating PA interventions that are enjoyable to ensure their effectiveness (Domville et al., 2019). Moreover, the use of accelerometry as a way to measure activity within intervention sessions provides more information than the logbooks previously used in the pilot study.

6.5.2 Body composition

Body mass increased in both groups across the study period, as would be expected with growth. However, no increase in body mass was found in the experimental group during the intervention period (pre to post), whilst the control group did. This suggests that the COPS intervention limited body mass gains during its implementation. No changes FM% or FFMkg were found, but the experimental group did have a decrease in BMI Z-score. A higher BMI Z-score is associated with greater mass compared to height for age and gender. Changes in body composition in children with OWB as a result of exercise intervention to improve postural stability and muscular strength similarly show changes in line with growth or no significant changes (Alberga et al., 2013; McGuigan et al., 2009; Sgro et al., 2009; Treuth et al., 1998). Longer durations of interventions (16 – 24 weeks) see changes in FFM (Sgro et al., 2009).

6.5.3 Physical well-being

There were no significant findings in pain or physical HRQoL. Similarly, Horsak et al. (2019) reported no change in self-reported pain in children and adolescents and OWB after an exercise program. Whilst positive effects on HRQoL have been observed from weight loss in pediatric obesity studies (Steele et al., 2016), the impact of resistance exercise interventions is less clear and sometimes not beneficial (Schranz et al., 2013). As discussed in Section 4.5.5, the reduction in physical HRQoL score in the pilot study was driven largely by participants' perceptions of ”being able to lift something heavy”. No change in the current study may suggest that positive psychological components of the current intervention, such as feelings of competency, changed participants' perceptions relative to the pilot study intervention.

Despite some main effects of time favouring the experimental group, increasing MVPA and decreasing sedentary time, no significant differences between time points were found. None of the previously reviewed studies (Section 1.4.1 and 1.4.2) regarding exercise interventions to improve postural stability and muscular strength also measured PA. Child OWB interventions that include educational, lifestyle and activity components have seen improvements in MVPA (Li et al., 2014; Trost et al., 2014), but this is not consistently found across PA and lifestyle intersection in children with OWB (Jurado-Castro et al., 2020). PA behaviour changes in children may require multi-component interventions and may also be influenced by socioeconomic and environmental barriers (Alcántara-Porcuna et al., 2022; Brockman et al., 2011; Kebbe et al., 2017). Additionally, if participants' increases in MVPA occurred in short, sporadical bouts (as is typical for children), these increases may have been diminished by the averaging out effect of using larger 60s epochs.

6.5.4 Physical function

6.5.4.1 Clinical measures of physical function

The experimental group demonstrated improved performance in STS repetitions and TUG tests from pre-intervention to follow-up, whilst the control group significantly declined. STS require adequate strength (typically associated with knee extension strength), muscular endurance, postural stability and cardiorespiratory fitness. As outlined in Section 6.4.4.2, there were no increases in absolute or scaled knee extension strength in the experimental group. Increases in STS performance may instead be related to improved muscular endurance, cardiorespiratory fitness or postural stability and the ability to control the CoM in the anterior-posterior direction during the sit-to-stand transition (Shumway-Cook et al., 2024). Whilst no improvements in mediolateral postural stability during walking (Section 6.4.4.3) and SLS balance tests were detected, the vertical and anterior-posterior movement of the CoM during STS may have improved. Moreover, given the lack of improvement in the 6MWT and gait speed, the increase in performance in the TUG test also suggests improvements in postural stability rather than direct increases in quadricep strength or walking speed. Additionally, improvements in STS and TUG may indicate enhanced motor coordination of the neuromuscular system following the intervention. The standing and sitting transitions in both tests, as well as the turning demands of the TUG test, require coordination between lower limb segments and the trunk (McMillan & Scholz, 2000; Shumway-Cook & Woollacott, 1985). The application of techniques such as vector coding and phase portraits in future research may be beneficial to examine the organization and coordination of movement in children with OWB and determine whether this should be a focus for intervention (Stergiou, 2004). Exercise interventions have shown improvements in motor skill battery tests, from which motor coordination is inferred (Han et al., 2018). However, the application of biomechanical analysis techniques to quantify coordination in children, and specifically in OWB compared to TW children, is lacking. Cardiorespiratory fitness was not assessed in the current study, but twice weekly sessions in which participants engaged in MVPA may have also improved exercise capacity. However, the mean improvements in performance were not substantial enough to meet the MDC thresholds outlined in Chapter 3.

6.5.4.2 Muscular Strength

Strength increases in the current study ranged from 0% to 23%, which is greater than that reported in the pilot study (Chapter 4 ~17%) and may suggest some beneficial effect of increased engagement in the co-produced intervention compared to the piloted intervention. However, this remains lower than the previously +20-30% reported for lower extremity-focused exercise programs in OWB youth (Horsak et al., 2019). This discrepancy may be due to the longer duration of the intervention (12 weeks) implemented by Horsak et al., as well as the intervention's targeted approach, which focused exclusively on two muscle groups and involved one-on-one sessions with therapist delivery. In contrast, the current study delivered a more varied, group-based intervention that targeted all lower limb muscle groups, potentially diluting the training effect for some muscles by comparison. Despite this, the current study found significant increases in absolute ankle dorsiflexion, hip abduction, hip adduction, and allometrically scaled ankle dorsiflexion, hip flexion, hip abduction, and hip adduction strength from pre-intervention. As previously noted (Chapter 3), frontal plane hip strength findings should be interpreted with caution, but the MDC thresholds previously set were reached for absolute hip extension strength and hip abduction strength, suggesting real increases in the experimental group beyond any measurement error. As discussed in Section 1.3.5, hip abductors play a crucial role in frontal plane stability during gait, and hip extensors act to control the forward progression of the body as the vertical GRF moves anterior to posterior (Figure 1-11 to 1-17). These factors combined may partially explain the improvements in STS and TUG test performance observed in the current study.

Increases in scaled hip adduction strength were large enough to show significant differences compared to the control group at post-intervention and follow-up. Typically, hip abductors are the target for improving frontal hip stability, but studies in adult populations show the hip adductors play a large role during dynamic balance (e.g. walking or tandem walking; Porto et al., 2019; Qiu et al., 2023). The inclusion of dynamic balance exercise in the current study (i.e. walking on beams, across balance pods, etc.) may have been effective in increasing adductor strength. The role of hip adductors in children and children with OWB's physical function is currently understudied. Additionally, despite non-statistical findings, mean experimental group increases from pre-intervention in hip extension and hip abduction were great enough to meet the MDC thresholds set out in Chapter 3.

6.5.4.3 Temporal-spatial measures of gait.

No changes in temporal-spatial parameters, such as walking speed and phase timing, suggest no change in stability strategies after the intervention (Browning, 2012; Molina-Garcia et al., 2019). Additionally, walking speed has been linked with ankle plantarflexion strength and kinematics (Anderson & Pandy, 2003). In the current study, there was no significant increase in ankle plantarflexion strength or sagittal ankle kinematics during gait in the experimental group after the intervention. Similarly, Horsak et al. (2019) found no benefit to temporal-spatial parameters following a 12-week exercise intervention. Short-term exercise interventions alone may not be enough to elicit changes in temporal-spatial parameters of gait, whilst exercise may increase maximal capacity (such as that tested in clinical physical function measures), adaptation to muscular strength and postural stability may not be sufficient to see significant changes during self-selected walking speeds.

6.5.4.4 3D gait analysis

Despite a significant increase in abduction strength in the experimental group, no changes were found in related gait parameters, such as frontal hip kinematics (Molina-Garcia et al., 2019). Singh et al. (2021) reported that knee extensor strength is most related to joint moments during gait in children with OWB, while hip adduction/abduction motion during gait is more closely related to adiposity. This may explain why increases in hip strength did not translate to changes in hip motion during gait. Conversely, Horsak et al. (2019), who also found significant increases in hip abduction strength, reported a significant decrease in maximal hip adduction during stance. However, these changes in frontal hip angle met the MDC thresholds set by the same authors. What is becoming evident is the presence of trends suggesting some beneficial outcomes from short-term (8–12 weeks) exercise interventions. However, more substantial and significant changes may require longer intervention periods, a greater number of participants, or more intensive (longer sessions or greater frequency) exercise sessions.

Midfoot eversion was reduced in the experimental group during the end of stance at follow-up compared to pre-intervention. Mahaffey et al. (2016) reported midfoot eversion to be significantly associated with increased FM% and, therefore, may suggest a beneficial effect of the intervention, therefore reducing the risk of foot pain and adverse loading. However, these findings should be interpreted with caution as MDC thresholds were not met. The experimental group increased internal transverse hip moments partway through midstance and into terminal stance at follow-up compared to pre-intervention. Shultz et al. (2009) found OWB to have greater peak external hip rotation (internal) moment during stance. The increase in external rotation moment in the current study may suggest an adverse effect of the intervention. However, despite the statistical significance, changes did not exceed the MDC, and the MDC% from Chapter 3 for transverse hip moment was 36% and; therefore, these changes should be interpreted with some caution.

No other significant gait changes were reported in the experimental group. Molina-Garcia et al. (2022) found that 13 weeks of neuromuscular exercise intervention (based on muscular strength, movement skill, and aerobic training) did not bring about significant changes in OWB 8-12-year-olds but did stop a significant decline in adverse gait patterns that was observed in the OWB control group. The control group in the current study showed no significant decline in gait biomechanics after eight weeks. Similarly, Horsak et al. (2019) reported that their control group also had no changes after 12 weeks. Longitudinal studies of child gait and function may benefit interpretation to understand the speed of decline relative to TW and active children.

6.5.5 Limitations

Conclusions about the effectiveness of the COPS intervention based on the current study are limited by the impact of school closures (which equated to > 35% of missed sessions) due to a period of teacher strikes and participant sickness (which equated to > 26% of missed sessions), particularly in the year immediately after Covid-19 shutdowns which diminished the total received intervention. However, whilst sickness will always be an uncontrollable factor, two uncommon events (Covid-19 and teacher strikes) had a significant impact on participants' ability to attend planned intervention sessions. Without Covid-19 increasing school absences and teacher strikes causing school closures, attendance would have been greater, and therefore the impact of the interevntion on outcome measures may have also been greater. Additionally, the findings in PA may have been confounded by the use of longer epoch lengths (60s), therefore averaging out any increases in shorter bursts of MVPA. However, changes in PA behaviour may require interventions that include multiple lifestyle components (Juardo-Castro et al., 2020).

6.5.6 Implications

Sustained within-session PA total activity and intensity throughout the intervention period and no negative impact on PA enjoyment or BPN as a result of the intervention, as well as no voluntary non-attendance to intervention sessions, cumulatively demonstrate the benefits of the COPS intervention to participants' positive experience of the intervention and PA in general, providing support for the holistic approach to intervention design. However, significant relationships between within-session PA and age and FM highlight areas that future development may need to focus on to improve engagement in older primary school children. Additionally, the findings demonstrate the beneficial effect of COPS intervention on measures of body composition, strength, and physical function, suggesting the inclusion of play activity with elements of resistance (e.g. sled pulling, step-up movements, etc.) has a beneficial effect on children with OWB and that this can be achieved in an autonomy-supportive and enjoyable environment for children with OWB. The current study also demonstrated the further work that is required to improve postural stability measures and physical well-being measures from school-based exercise interventions. Additionally, well-being appears to be unaffected by short exercise interventions and increases in physical function, which may have some ramifications on the theorised relationship between OWB, physical function and physical well-being (Figure 1-28). More intervention research is required to better determine the nature of the relationship between OWB, physical function and physical well-being.

6.6 Conclusion

Implementation of the co-produced intervention was successful, and findings from attendance and session accelerometry data show a positive effect from the co-production development (Chapter 5) relative to the original piloted intervention (Chapter 4). However, the delivery of the intervention was impacted by wider contextual factors within the school environment (e.g., school closures), which reduced the number of total delivered sessions and may have impacted the intervention's effectiveness in physical well-being and physical function. The positive findings in enjoyment, need satisfaction, and intervention activity levels (which remained consistent throughout the intervention period) provide support for the application of SDT to intervention development and design. Future research should build upon these findings and address some of the contextual issues of working with schools to improve intervention delivery. Any positive mean changes in physical well-being measures did not meet statistical significance, and therefore, it cannot be concluded that the currently delivered intervention is beneficial to physical well-being in OWB 7–11-year-olds within the study period. Whilst questionnaire data, and specifically PA data, are likely impacted by limited participant numbers in the current study, significant changes in physical well-being and particularly PA behaviour may take longer to occur than was investigated in the current study.

The intervention was successful in increasing lower limb strength around the hip and ankle, and positive changes were seen in clinical physical function tests (TUG and STS) for the experimental group. These are promising results from the novel co-produced intervention delivered in the current study. However, despite the positive outcomes in strength and clinical physical function tests, 3D gait analysis and examination of CoM during stance showed no beneficial outcomes. Therefore, associations between increasing strength and gait function in children with OWB are not established in the current study. Future work may include an analysis of coordination to examine physical function in children with OWB. Improvements in STS and TUG tests, with no improvement in measures of gait stability, walking speed, or knee extensor strength (some of the key components in STS and TUG performance), suggest improvements in other motor control or motor organisation mechanisms.

The current study is the first intervention study in children with OWB to combine physical well-being and physical function measures to begin to add to the body of research that exists examining the interrelated components of children with OWB's health and function. School-based co-produced exercise intervention is beneficial for improving some lower limb strength measures and measures of physical function in children with OWB. However, more work is required to fully understand these beneficial changes and to positively impact physical well-being.

7 General Discussion

The aims of this thesis were: 1) to assess the reliability and change statistics of key physical function measures, including isokinetic dynamometry, biomechanical dynamic postural stability, and gait assessment in children with overweight and obesity (OWB) and typical weight (TW) children; 2) To design, pilot, and refine a feasible, school-based exercise intervention aimed at improving postural stability and muscular strength in children with OWB, while also addressing the psychological needs of children with OWB; and 3) To evaluate the effectiveness of that intervention (*C*o-produced with children with OWB targeting *P*osture stability and muscular *S*trength [COPS]) to improve postural stability and muscular strength, and to determine its impact on physical well-being and physical function in children with OWB.

Thesis Aim 1.

The reliability of various physical function, gait and strength measures was evaluated in OWB and TW children to firstly provide novel information on measurement error in the population of interest (OWB children) in relation to a commonly researched population (TW children) and secondly, to inform meaningfulness of later statistical findings on the effectiveness of the exercise intervention (Chapter 6). Test-retest reliability statistics differed between OWB and TW participants, with OWB demonstrating a higher intraclass correlation coefficient (ICC) and less variability in lower limb 3D gait kinetics and kinematics. The findings of the study suggested that improvements seen in retest performance of physical function measures in TW from learning are negated in OWB, who may be limited in their maximal performance (due to obesity-related constraints), which then negates any effect of learning. Interestingly, standard error of measurement (SEM) analysis of whole waveforms also highlighted the greater variability of waveforms around stance transitions. During stance phase transitions (e.g. from single stance to double stance), stability is disturbed as CoM and base of support move, and the body needs to control and transfer energy from ground contact (Figure 1-11). Understanding mechanisms to manage stability around these challenging transitions may provide more information on children with OWB's function during gait.

The change statistics from Chapter 3 provided a meaningful reference for change, which, when applied to statistically significant findings, reframed the interpretation of some results (Chapter 6). For example, the gait changes observed in the experimental group (Section 6.4.4.7) at transverse hip moments were statistically significant. However, the direction of these changes could be considered to suggest an unfavourable effect of the intervention. However, when compared to the change statistics derived from the reliability study, the thresholds of “real change” were not met, meaning these should be interpreted with some caution. Additionally, the use of minimal detectable change (MDC) thresholds suggested increases in hip extension and hip abduction that were not revealed from statistical analysis alone.

Additionally, the reliability study highlights the large heterogeneity in data from children, partly due to the broad range of age, maturity, and physical ability. Children’s motivation and feelings on the day of data collection may have also significantly impacted the reliability statistics. Whilst this variability influenced reliability statistics, it may also reasonably be assumed to impact the assessment of change over repeated measures pre-, post-intervention, and follow-up. While it cannot be assured that changes in children’s motivation and feelings on testing days to perform maximally were consistent across the reliability study (Chapter 3) and the intervention study (Chapter 6), any variability observed in the reliability study, due to fluctuating motivation, is accounted for in the change statistics applied to the intervention study. This approach partially mitigates the potential impact of varying motivation quality on the interpretation of intervention outcomes.

Chapter 4 highlights the need for reliability to be evaluated within the specific population of interest, as in this case, OWB-related factors, such as the reduced capacity to work maximally, alter measurement consistency. Conversely, TW children may experience greater learning effects, which also influence reliability outcomes, which may make them inappropriate to apply to OWB groups. Future research may consider the importance of incorporating familiarisation and practice sessions, as well as exploring testing strategies outside of controlled laboratory environments, to enhance measurement reliability.

Thesis Aim 2.

The second aim of the thesis was primarily addressed in Chapters 4 and 5. Piloting the intervention studies was essential to examine the logistics of data collection protocols, intervention feasibility, and the practicalities of visiting schools and hosting university laboratory sessions. This process determined key logistical points for the COPS intervention study (Chapter 6) and provided focus areas for further development of the intervention. Feedback from the pilot intervention and the rich data collected during the co-production study contributed to the emerging body of work that seeks to include the voices of the target population (Ells et al., 2018; Smith et al., 2023). As evidenced by the findings in Section 6.4.1, significant improvements were observed in children's willingness to attend intervention sessions and their engagement during these sessions. The current work highlights the negative effect that controlling environments can have on children with OWB's motivation to engage in physical activity (PA). The pilot intervention was rigorous and theoretically sound, but the controlling environment did not meet the needs of children with OWB to foster motivation and enjoyment. In contrast, the COPS intervention (discussed in Section 6.4.1) generated greater activity levels than a typical structured PE lesson, and this activity was maintained throughout the intervention. This success is likely attributed to allowing participants to have more freedom and to conduct activities in a play-like way during intervention sessions. Children are generally more active during active play in school or free time, as play is often intrinsically motivated and free from adult control (Brockman et al., 2011). It is, therefore, easy to understand why active play generates greater activity in children. However, unstructured active play lacks the format and focus required for specific outcomes such as improved lower limb strength and postural stability.

The approach taken with the developed intervention was one of guided and focused play. This method increased engagement during sessions and produced some beneficial outcomes in body mass, body mass index (BMI) Z-score, lower limb strength and physical function. However, there is an argument regarding the differences between play that promotes healthy behaviours versus play that children engage in purely for enjoyment and children's perception of those two different types of activity (Alexander et al., 2014). What cannot be ascertained from the current work, and as such may warrant further investigation, is understanding what might be lost and gained when interventions, such as the one developed here, compromise the rigidity of theoretically applied training models for increasing strength and postural stability development, to allow for increased engagement through play. This guided play approach, while effective in maintaining focus on intervention outcomes, may lose some of the intrinsic motivation that characterises free play. Either of the compromises may then dilute beneficial outcomes (which may partly explain some of the lack of significant findings on physical well-being and gait post-intervention in Chapter 6), meaning that interventions may need to be implemented over longer periods or have more frequent sessions within the same period to account for any lack of focus and intensity provided from traditional resistance or exercise programmes.

Teachers were underutilised during the piloting and co-production phases of the thesis. During the initial pilot study, the recruited school provided some input on the feasibility of data collection protocols and intervention delivery (namely, what would be feasible in taking children out of normal school activities). While it is essential to include the target population in the development process, it is equally important to involve those who act as gatekeepers to successful intervention research, such as parents and teachers (O'Mara-Eves et al., 2022). Clifford et al. (2023) included four workshops with school leaders, teachers and PE specialists in the development of a school-based PA programme. However, Clifford et al. (2023) noted significant challenges with engaging teachers due to curriculum time demands. The inclusion of teachers in the current work was not feasible given the timeline for completion and the narrow aim of the co-production process (i.e. development of the intervention specifically for the needs of children with OWB). Engagement with teachers in future work may require an education component, as teachers may not value PA or lack confidence in contributing to such interventions if they are not PE specialists (Alcántara-Porcuna et al., 2022). Including teachers more effectively in future interventions could address some of the contextual issues identified in intervention delivery. The implemented COPS intervention (Chapter 6) lost several planned delivery sessions due to a lack of space in the school. The scheduling of PA and PE space for other activities demonstrates the prioritisation and value of not only research but PA as a whole, and therefore, the inclusion of teachers in future work may provide better buy-in from those schools and teachers engaged in PA programmes.

Few studies have explored the experiences of children with OWB participating in exercise interventions. This work offers valuable insights from the participants' perspectives, shedding light on intervention-specific factors that impact applicability and effectiveness. The inclusion of children in the development of the COPS intervention provided rich information that aided in the development of a participant-focused, novel and effective exercise intervention. If target populations are unwilling to engage with an intervention, regardless of its potential effectiveness for adaptation, its applicability and impact in real-world settings will be significantly limited. This is particularly important in children with OWB, as children are generally less likely to engage in activities they do not enjoy, even if they are beneficial, and those with OWB experience physical constraints and psychological and social factors that may already have a negative impact on PA. Therefore, future research should consider the inclusion of children with OWB and other stakeholders important to the success of intervention design and implementation.

Thesis Aim 3.

The first two thesis aims, addressed in Chapters 3, 4, and 5, provided the foundation for the successful implementation and assessment of the school-based intervention study. The COPS intervention in Chapter 6 found several beneficial effects in the experimental group, including the reduction in BMI Z-score and no increase in body mass during the intervention period, whilst the control group increased. The COPS intervention successfully improved lower limb strength (although not in all targeted muscle groups). The effect of resistance training in OWB youth has an established benefit to muscular strength as measured by one repetition maximum (1RM), isometric knee extension, and hand grip strength (Schranz et al., 2013). To the author's knowledge, the work presented here is the first to report intervention effects on lower limb muscular strength around the ankle, knee, and hip in children with OWB. Indeed, despite a lack of attendance and adherence, the pilot intervention also found some benefit to lower limb muscle strength across time in the experimental group, whilst none was found in the control group. In both the pilot study (Chapter 4), COPS intervention (Chapter 6) and previously reported resistance training studies, changes in strength occurred without significant increases in fat-free mass (FFM; Chapters 4, 6; Schranz et al., 2013). Increases in strength are likely to be the result of adaptation in neuromuscular function rather than increases in muscle size. Therefore, the effectiveness of exercise interventions should be determined by physical function and performance measures and not just from FFM accrual or body composition changes.

Findings from Chapter 6 provide further support for the use of the COPS exercise intervention to improve strength in children with OWB. However, the findings in Chapter 6 on balance and postural stability post-intervention lacked statistical significance. Previous studies that demonstrated improvements in postural stability measures in children with OWB were conducted over longer (3-6 months) intervention periods (Kuni et al., 2015; Nobre et al., 2017) and analysed only with those participants obtaining a minimum 85% attendance rate (Guzmán-Muñoz et al., 2019), which was greater than the average (72.28%) in the COPS intervention. Therefore, the lack of findings in postural stability may be due to insufficient load. As discussed in Section 6.5.4.1, improvements in sit-to-stand (STS) and timed-up-and-go (TUG) tests may have been driven by a combination of muscular strength and unmeasured aspects of motor control, such as anterior-posterior CoM control or interlimb coordination. Mediolateral postural stability has been identified to be of greater impairment in OWB paediatric populations (McGraw et al., 2000). Hence, the focus on mediolateral postural stability within the current work. However, regarding some physical function tasks (such as those including STS transitions), anteroposterior CoM control may be an explanatory factor for performance in these tasks. Furthermore, there is currently no available data on interlimb coordination in OWB and TW children during physical function tasks, such as STS transitions or walking. This lack of data precluded its inclusion in the current work as a possible mechanism for improving physical function. Future research may explore whether interlimb coordination is a relevant area of investigation in children with OWB and a potential focus for intervention development.

A novel contribution of the current work is the examination of physical well-being measures in relation to an exercise intervention aimed at improving physical function in children with OWB. Significant improvements in body mass, BMI Z-score, muscular strength and physical function test (STS and TUG) performance were observed after the COPS intervention. These findings provide support for the theorised links between strength, and physical function in children (Faigenbaum et al., 2023). However, non-significant findings in physical well-being (pain, physical health-related quality of life [HRQoL] and PA behaviour) suggest that the theorised relationship between improving physical function and physical well-being from short-term exercise intervention in children with OWB presented in Chapter 1 requires more research. Changes in measures of physical well-being may take longer to manifest than the relatively short intervention and follow-up period in Chapter 6, or there may be additional individual (e.g. low level of systemic inflammation in relation to pain, motivation to be active in free time) and environmental factors (e.g. availability of time, space and resources to be active) that require focus in future research.

As previously discussed, while the redesign of the pilot to become the COPS intervention successfully increased engagement, its effectiveness in producing significant improvements in strength and postural stability may have been diluted. This is likely due to the less controlling, more play-like nature of the activities, which allowed children greater choice, as well as contextual factors that limited the delivery of all 16 planned intervention sessions. Research by Schranz et al. (2013) suggests that achieving significant improvements in strength and postural stability may require a minimum number of exercise hours (>25 hours having the greatest effect on strength). While the development of the COPS intervention initially addressed engagement issues in the pilot, future work may need to consider longer-duration interventions to ensure adequate workload and intensity for strength and postural stability development.

Participant motivation and feelings on the day of data collection may also have influenced study findings. While participant- and protocol-specific reliability and change statistics account for some variability, unforeseen factors emerged during the intervention that were not present in the pilot study. For example, Ramadan, the month of daytime fasting in the Muslim faith, coincided with the post-intervention data collection period in 2023. Although fasting is not typically required for children under 14, several participants in the intervention group chose to fast. This may have affected their ability to perform maximally during physical tasks. This issue did not arise in the pilot study for two reasons: Ramadan occurred later in the year, and the schools involved in the pilot and co-production phases were predominantly Catholic. This highlights the importance of engaging with diverse schools and communities to anticipate such contextual factors in future research.

The sample size estimates determined in the reliability study were met for the intervention group in the COPS intervention study (Chapter 6). However, participant dropouts over the three testing time points (n = 7 across both groups, primarily due to illness) led to uneven and reduced final sample sizes. As outlined previously, resource restrictions imposed by schools during piloting further compounded these issues. For example, schools required that all pre-, post-intervention, and follow-up testing occur on a single day, without opportunities to retest absent participants. This was due to the challenges of taking children out of normal school activities and staffing constraints for off-site visits. The implementation of the co-produced intervention study occurred in the years immediately following the reopening of schools after the COVID-19 pandemic lockdowns. Not only was recruitment initially impacted as schools and parents were reluctant to take part in anything deemed as an unnecessary risk, but also to take time away from being back in face-to-face teaching after so much time away from the classroom environment. The COVID-19 pandemic changed the landscape in which this research occurred compared to the pilot intervention. This created unforeseen and uncontrollable limiting factors to participant recruitment and retention.

To address these challenges in future research, and to expand this work, non-laboratory-based measures could be considered. In this study, laboratory-based measures, such as 3D gait analysis and isokinetic dynamometry, were chosen as the gold standard for assessing outcomes. However, future work could investigate the validity of alternative measurement techniques, such as accelerometry-based tools or markerless 3D gait analysis, against these established methods in children with OWB. By adopting these less resource-intensive approaches, the burden on participating schools could be reduced, making the research more accessible and scalable.

8 Thesis conclusion

The presented thesis provides child- and overweight and obese-specific reliability and change statistics for both laboratory and clinical measures of physical function. These findings addressed critical gaps in the existing literature, offering thresholds that can inform interpretation in future intervention studies. Such contributions are essential for future assessment of interventions in children with overweight and obesity (OWB) to ensure findings are for real change in children with OWB beyond that of statistical significance.

This research also contributes to the growing body of contextual knowledge regarding the challenges of engaging children with OWB in exercise interventions. Barriers to successful exercise intervention engagement were identified and add to a large body of previous work that supports the application of self-determination theory (SDT) to children's physical activity (PA) motivation. A key strength of the study lies in its demonstration of the benefits of engaging children in the intervention design process. By incorporating the perspectives and preferences of the target population, the *C*o-produced with children with OWB targeting *P*osture stability and muscular *S*trength (COPS) intervention adopted a more holistic, child-centred approach that enhanced engagement and created an enjoyable and impactful environment. The work provides practical insights for designing school-based exercise interventions in OWB and highlights area for future engagement work so that interventions are not only effective but also sustainable in real-world settings. This is particularly significant given the critical need for inclusive, accessible strategies to combat the growing prevalence of childhood obesity.

The thesis also contributes to theoretical discussions surrounding the relationship between physical function and physical well-being in children with OWB. Whilst the proposed link between poor physical function and reduced well-being is well documented in cross-section work, the current work suggests that this relationship may be more nuanced and, as such, further work is required to investigate this. Specifically, short-term exercise programs may not directly influence physical well-being through improvements in physical function, highlighting the complexity of these interactions in children with OWB. These findings underscore the need for future research to explore the interplay between PA, function, and well-being in greater depth, particularly over longer intervention periods.

This thesis makes significant contributions to the understanding of physical function and intervention design in children with OWB. Several beneficial outcomes in body mass, BMI Z-Score, strength and physical function were found as a result of the COPS intervention. It bridges key gaps in the literature and provides practical recommendations for improving engagement. Collectively, this work lays a foundation for future research and supports the development of more effective, inclusive, and contextually relevant interventions for improving the health and well-being of children with OWB.

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Appendicies

Appendix A. PedsQL Paediatric Pain Questionaire

PedsQL™

Paediatric Pain Questionnaire™

Young Child Form (**5-7** years of age)

Name: ____

Date: ______________ **Record Number:** ______________________________

What words would you use to describe your pain or hurt?

____

____

____

1. Put a mark on the line that best shows **how you feel now**. If you have no pain or hurt, you would put a mark at the end of the line by the happy face. If you have some pain or hurt, you would put a mark near the middle of the line. If you have a lot of pain or hurt, you would put a mark by the sad face.

☺ |————————————————————| ☹

Not hurting **No discomfort** **No pain**	**Hurting a lot** **Very uncomfortable** **Severe Pain**

2. Put a mark on the line that best shows what was the **worst pain you had over the last 7 days**. If you had no pain or hurt over the last 7 days, you would put a mark at the end of the line by the happy face. If you had some pain or hurt, you would put a mark by the middle of the line. If the worst pain you had was a lot of pain, you would put a mark by the sad face.

☺ |————————————————————| ☹

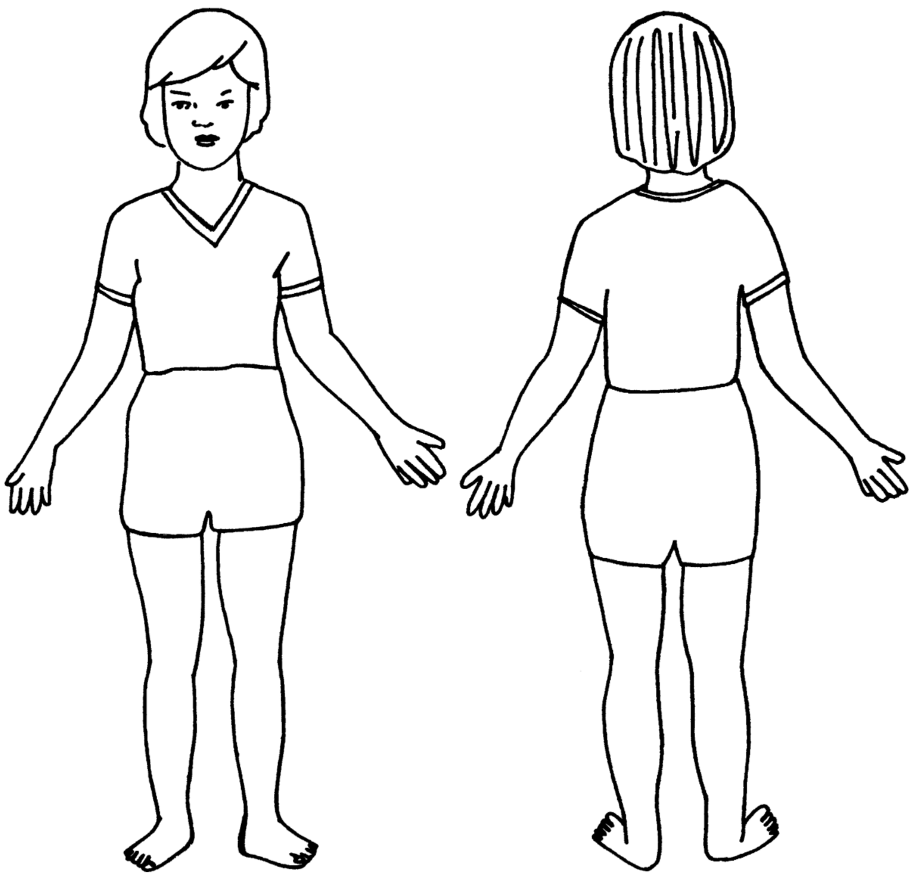
Not hurting **No discomfort** **No pain**	**Hurting a lot** **Very uncomfortable** **Severe Pain**

PedsQL PPQ - (5-7) Not to be reproduced without permission Copyright © 1998 JW Varni, PhD. All rights reserved

PedsQL ™ Pediatric Pain Questionnaire - Young Child (5-7) - UK/English - Version of 30 May 08 - Mapi Research Institute.
ID4627 \ PedsQoL-PPQ-YC-AU4.0eng-GBq.doc

Pick the colours that mean **No hurt, A little hurt, More hurt,** and **A lot of hurt** to you and colour in the boxes. Now, using these colours, colour in the body to show how you feel. Where you have no hurt, use the **No hurt** colour to colour in your body. If you have hurt or pain, use the colour that tells how much hurt you have.

No pain No hurt	Mild pain A little hurt	Moderate pain More hurt	Severe pain A lot of hurt



Front Back

PedsQL PPQ - (5-7) Not to be reproduced without permission Copyright © 1998 JW Varni, PhD. All rights reserved

ID# ___________________________

Date:__________________________

PedsQL ™

Pediatric Quality of Life Inventory

Version 4.0

CHILD REPORT (ages **8-12**)

DIRECTIONS

On the following page is a list of things that might be a problem for you.
Please tell us **how much of a problem** each one has been for you during the **past ONE month** by circling:

0 if it is **never** a problem
1 if it is **almost never** a problem
2 if it is **sometimes** a problem
3 if it is **often** a problem
4 if it is **almost always** a problem

There are no right or wrong answers.
If you do not understand a question, please ask for help.

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*In the past **ONE month**, how much of a **problem** has this been for you …*

ABOUT MY HEALTH AND ACTIVITIES ***(problems with…)***	**Never**	**Almost Never**	**Some-times**	**Often**	**Almost Always**
1. It is hard for me to walk more than one block	0	1	2	3	4
2. It is hard for me to run	0	1	2	3	4
3. It is hard for me to do sports activity or exercise	0	1	2	3	4
4. It is hard for me to lift something heavy	0	1	2	3	4
5. It is hard for me to take a bath or shower by myself	0	1	2	3	4
6. It is hard for me to do chores around the house	0	1	2	3	4
7. I hurt or ache	0	1	2	3	4
8. I have low energy	0	1	2	3	4

ABOUT MY FEELINGS ***(problems with…)***	**Never**	**Almost Never**	**Some-times**	**Often**	**Almost Always**
1. I feel afraid or scared	0	1	2	3	4
2. I feel sad or blue	0	1	2	3	4
3. I feel angry	0	1	2	3	4
4. I have trouble sleeping	0	1	2	3	4
5. I worry about what will happen to me	0	1	2	3	4

HOW I GET ALONG WITH OTHERS ***(problems with…)***	**Never**	**Almost Never**	**Some-times**	**Often**	**Almost Always**
1. I have trouble getting along with other kids	0	1	2	3	4
2. Other kids do not want to be my friend	0	1	2	3	4
3. Other kids tease me	0	1	2	3	4
4. I cannot do things that other kids my age can do	0	1	2	3	4
5. It is hard to keep up when I play with other kids	0	1	2	3	4

ABOUT SCHOOL ***(problems with…)***	**Never**	**Almost Never**	**Some-times**	**Often**	**Almost Always**
1. It is hard to pay attention in class	0	1	2	3	4
2. I forget things	0	1	2	3	4
3. I have trouble keeping up with my schoolwork	0	1	2	3	4
4. I miss school because of not feeling well	0	1	2	3	4
5. I miss school to go to the doctor or hospital	0	1	2	3	4

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Appendix C. Ethical approval for reliability of physical function measures in overweight and obese children.

St Mary's University Twickenham London
Faculty of Sport, Health & Applied Science

8 July 2020

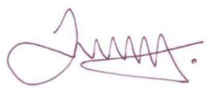
Dear Megan Le Warne,

Re. Development of a best-evidence foot and lower limb intervention programme designed to improve musculoskeletal health in children – Reliability Study

Thank you for submitting your ethics application for consideration.

I can confirm that your application has been considered by the SHAS Ethics Committee and that ethical approval is granted. Please find attached your signed approval form.

Yours sincerely,



Jamie North

Faculty of SHAS Ethics Committee

Appendix D. Example parental and child information and consent forms for reliability of physical function measures in overweight and obese children.

St Mary's University Twickenham London

We would like to invite your child to participate in a research project being undertaken as part of a Doctoral research project at St Mary's University Twickenham. This form provides you with all the information about the study so you can make an informed decision as to whether your child can participate. This research has received formal approval from the St Mary's University Twickenham Ethics Committee. All researchers have completed Disclosure and Barring Service checks.

Project details
Physical function is an essential part of daily living. In research and clinical practice performance measures (such as balancing) are used to assess someones ability to do everyday physical tasks. This research project aims to test the reliability of these measures (that is if the same person does the same test twice, they will get the same result). We are looking for boys and girls between 7 and 11 years old to take part in our study. The project will consist of completing some physical tasks such as walking and balancing, and a short questionnaire. We would require you and your child to visit St Mary's campus to complete these tasks twice, one week apart. Details of these tasks can be found on the next page.

Confidentiality of the data
Information collected about your child will be stored on computers with security passwords. Only the principal researcher and his research team have access to review these research records. This data will be kept for ten years in line with St Marys University data guidelines. Children will remain anonymous in any report and no identifiable information used

Disclaimer
Your child is not obliged to take part in this study, and you are free to withdraw at any time during tests. Should you choose to withdraw from the programme, you may do so without disadvantage to yourself or your child and without any obligation to give a reason.

Details of the tests we will complete.

These are expected to take approximately 90mins in total.

Gait Analysis - Your child will be asked to walk through the laboratory with sticky reflective markers attached to their legs and feet giving information on the movement of the limbs as the child walks, see figure 1. The small pieces of equipment attached to the skin of your child might feel a little odd for them, but it will not hurt, and they can be removed easily. Your child will be asked to wear shorts for this part of the study in order for us to see the reflective markers.

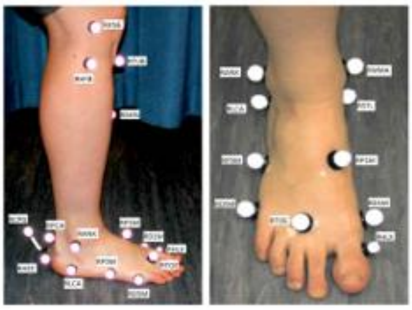


Figure 1. Reflective markers

Figure 2. Example of the dynamometer

Muscle strength testing – This will be performed on an isokinetic dynamometer, see figure 2. Your child will be asked to squeeze their leg muscles as hard as they can, this will be repeated with rest periods in between. After testing muscle strength, the child's muscles may be a little sore, similar to after playing sport, but this will disappear within 48 hours.

Foot pressure measurements - For this your child will be asked to stand and walk across a pressure pad barefooted.

Clinical assessments - This requires your child to fill in a short questionnaire about any pain they feel whilst doing exercise and to do a number of easy functional movements such as single leg balance, getting up and sitting back down in a chair, and walking for six minutes.

Children will be given plenty of rest throughout all testing procedures. Although highly unlikely, if at any point your child should feel ill or is injured, the exercise or test will stop immediately trained first aider will be present and parent, guardian or teacher will be notified immediately.

YOU WILL BE GIVEN A COPY OF THIS FORM TO KEEP TOGETHER WITH A COPY OF YOUR CONSENT FORM

St Mary's University Twickenham London

Name of Participant: ____

Development of a best-evidence foot and lower limb intervention programme designed to improve musculoskeletal health in children.

Ryan Mahaffey ryan.mahaffey@stmarys.ac.uk
Megan Le Warne megan.lewarne@stmarys.ac.uk

- I agree to my child taking part in the above research. I have read the Participant Information Sheet, which is attached to this form. I understand what my child's role will be in this research, and all my questions have been answered to my satisfaction.
- I understand that I am free to withdraw my child from the research at any time, for any reason and without prejudice.
- I have been informed that the confidentiality of the information my child and I provides will be safeguarded.
- I am free to ask any questions at any time before and during the study.
- I have been provided with a copy of this form and the Participant Information Sheet.

Data Protection: I agree to the University processing personal data which my child and I have supplied. I agree to the processing of such data for any purposes connected with the Research Project as outlined to me.

Name of parent (print)……………………………………………………………………………….

Signed………………………………………… Date……………………………………........

If you wish to withdraw your child from the research, please complete the form below and return to the main investigator named above.

Development of a best-evidence foot and lower limb intervention programme designed to improve musculoskeletal health in children.

I WISH TO WITHDRAW MY CHILD FROM THIS STUDY

Name of Participant: ____

Name of Parent ____

St Mary's University Twickenham London

CONFIDENTIAL VOLUNTEER MEDICAL QUESTIONNAIRE FORM

Name: Age: Gender:

Please give details to help us in assessing your child's possible participation in the project.
Please answer the following questions:

Does your child have a condition which affects their feet (including verruca's, athletes foot, toe nail infections etc.)?	YES / NO
Does your child have a condition which affects their coordination or movement.	YES / NO
Does your child currently have a fever or feelings of being generally unwell?	YES / NO
Does your child have any foot, ankle or leg pain when walking?	YES / NO
Has your child had surgery or Chronic Illnesses? (some examples of chronic conditions include, but are not limited to): Asthma, Diabetes, Cerebral palsy, Epilepsy, Congenital heart problems	YES / NO
Has your child had any foot, ankle or leg injuries?	YES / NO
Has your child had any allergies?	YES / NO
Is there any other reason why your child should not participate in this study?	YES / NO

Name of Participant	Date	Signature (parent)
……………………………..	……………………………..	……………………………..
Name of Researcher	Date	Signature
……………………………..	……………………………..	……………………………..

Research Project

Hi, my name is Megan and I am collecting some information to be used in a project.

I would like to ask you some questions about yourself and do some activities like walking, balancing, standing and sitting.

It will take about 25mins, and we will do the same again next week.

If you want to stop at any point, then just tell me.

It is up to you if you would like to take part. If you do, please fill in the form below.

I would like to take part

Please write your name…………………………

Appendix E. Ethical approval for Pilot study of a school-based exercise programme with overweight and obese children.

St Mary's University Twickenham London

17 December 2018 SMEC_2017-18_105

Megan Le Warne (SHAS): 'Development of a best-evidence foot and lower limb intervention programme designed to improve musculoskeletal health in obese children'

Dear Megan

University Ethics Sub-Committee

Thank you for re-submitting your ethics application for consideration.

I can confirm that all required amendments have been made and that you therefore have ethical approval to undertake your research.

Yours sincerely

Dr Jamie North
Chair, Ethics Sub-Committee

Cc Dr Ryan Mahaffey

St Mary's University, Waldegrave Road, Strawberry Hill, Twickenham, London TW1 4SX
Switchboard 020 8240 4000, Fax 020 8240 4255, www.stmarys.ac.uk

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Registered Office Waldegrave Road, Strawberry Hill, Twickenham TW1 4SX. Registered Charity Number 1120192

Appendix F. Example parental and child information and consent forms for pilot study and related focus groups

We would like to invite your child to participate in a research project being undertaken as part of a Doctoral research project at St Mary's University, Twickenham. This form provides you with the information about the study so you can make an informed decision as to whether your child can participate. It also informs you of how your child's privacy will be protected and what your child's involvement will be if you agree they can take part. Your child's participation is voluntary and you can withdraw your child from the research at any time without giving any reason and this will not affect the status of your child's medical care or legal rights. To take part in the study you will be asked complete a confidential health questionnaire on behalf of your child. This research has received formal approval from the St Mary's University Twickenham Ethics Committee. All researchers have completed Disclosure and Barring Service checks.

Your participation in the research project
We are looking for boys and girls between 7 and 11 years old to take part in our study. This will consist of 3 visits to in Twickenham, and a 2-month period each.

Confidentiality of the Data
Information collected about your child will be stored on computers with security passwords. Only the principle researcher and his research team have access to review these research records. This data will be kept for 10 years in line with St Marys University data guidelines. Children will remain anonymous in any report and no identifiable information used.

Disclaimer
Your child is not obliged to take part in this study, and you are free to withdraw at any time during tests. Should you choose to withdraw from the programme you may do so without disadvantage to yourself or your child and without any obligation to give a reason.

Dear Parent/Guardian

As part of the project with St Mary's University Twickenham, we would like to get feedback from your child about their experience on the programme. This will take place on Friday 5th April during the school day and take up to 45 mins.

During this time, they will be asked to fill in a questionnaire designed to tell us how much they enjoyed it, and also take part in a focus group discussion. The focus group discussion will include activities such as drawing their favourite exercise they did whilst talking about aspects they liked or didn't like. This session will be led by one the research team and audio recorded, no video recording will be taken.

Information collected about your child will be stored on computers with security passwords. Only the principal researcher and his research team have access to review these research records. This data will be kept for 10 years in line with St Marys University data guidelines. Children will remain anonymous in any report and no identifiable information used.

Regards

Ryan Mahaffey

Testing to be completed at St Mary's University Twickenham – this will occur 3 times.

Activity Monitoring – Your child will be asked to wear an accelerometer (figure 2) for 7 consecutive days to measure how much physical activity they would usually perform. This is a small activity tracker device similar to a fitbit.

Figure 2. Accelerometers used to measure physical activity

Body Composition – Your child's height and weight will be measured, and body composition measured using a bioelectrical impedance machine. This requires your child to lay down for 5 mins. Two stickers will be placed on the hands and feet and a small machine attaches to these by clips and the measurement is taken while your child lays still for approximately 30 seconds. Children will feel nothing whilst the measurement is taken. These measurements are safe and work similarly to bathroom scales that also measure muscle mass and fat mass.

Gait Analysis - Your child will be asked to walk through the laboratory with sticky reflective markers attached to their legs and feet giving information on the movement of the limbs as the child walks, see figure 3. The small pieces of equipment attached to the skin of your child might feel a little odd for them, but it will not hurt, and they can be removed easily. Your child will be asked to wear shorts for this part of the study in order for us to see the reflective markers.

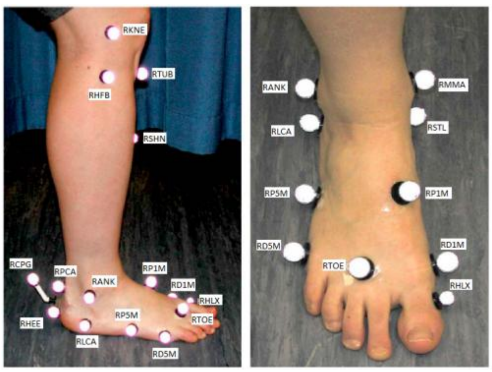


Figure 3. Showing the markers

Figure 4. Example of the dynamometer

Muscle strength testing – This will be performed on an isokinetic dynamometer, see figure 4. Your child will be asked to squeeze their leg muscles as hard as they can, this will be repeated with rest periods in between. After testing muscle strength, the child's muscles may be a little sore, similar to after playing sport, but this will disappear within 48 hours.

Foot pressure measurements - For this your child will be asked to stand and walk across a pressure pad barefooted.

Clinical assessments - This requires your child to fill in a short questionnaire about any pain they feel whilst doing exercise and to do a number of easy functional movements such as single leg balance, getting up and sitting back down in a chair, and walking for six minutes.

Physical activity enjoyment questionnaire – This requires your child to fill in two short questionnaires about physical activity. Example questions include stating of they agree a lot, agree, neither agree or disagree, disagree, or disagree a lot to statements such as "I feel I do well", "We do activities which I also would choose myself" and "I enjoy it".

Children will be given plenty of rest throughout all testing procedures. Although highly unlikely, if at any point your child should feel ill or is injured, the exercise or test will stop immediately trained first aider will be present and parent, guardian or teacher will be notified immediately.

Research Project

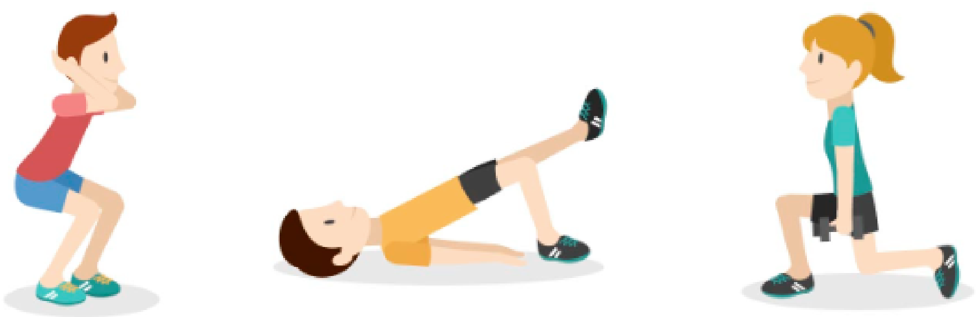
Hi, my name is Megan and I am collecting some information to be used in a project.

This piece of research is tying to find out if we can change how some boys and girls walk.

We would like to measure -

- How strong you are and how you walk.
- Measure your height, weight and the size of your feet
- Ask you to walk for 6 minutes and time you getting up from a chair.
- And wear an activity monitor to see how much you move day to day.

And we would also like to take you and your class through some exercises like below. This will take place in your school over several weeks.



This will happen over several weeks, and if you want to stop at any time then just tell me.

St Mary's University Twickenham London

Name of Participant: ____

Development of a best-evidence foot and lower limb intervention programme designed to improve musculoskeletal health in children.
Megan Le Warne – Megan.lewarne@stmarys.ac.uk

Members of the research team: Megan Le Warne, Jourdana Durrell, Ryan Mahaffey.

1. I agree to my child taking part in the above research. I have read the Participant Information Sheet which is attached to this form. I understand what my child's role will be in this research, and all my questions have been answered to my satisfaction.
2. I understand that I am free to withdraw my child from the research at any time, for any reason and without prejudice.
3. I have been informed that the confidentiality of the information I and my child provides will be safeguarded.
4. I am free to ask any questions at any time before and during the study.
5. I have been provided with a copy of this form and the Participant Information Sheet.

Data Protection: I agree to the University processing personal data which I and my child have supplied. I agree to the processing of such data for any purposes connected with the Research Project as outlined to me.

Name of parent
(print)……………………………………………………….…………………………..

Signed………………..…………………
Date……………………………........

If you wish to withdraw your child from the research, please complete the form below and return to the main investigator named above.

Title of Project: Development of a best-evidence foot and lower limb intervention programme designed to improve musculoskeletal health in children.

I WISH TO WITHDRAW MY CHILD FROM THIS STUDY

Name of Participant:
____

Name of Parent
____

Signed: __________________________________ Date: _____________________

Appendix G. Ethical approval for A co-production approach to development of a school-based exercise intervention.

St Mary's University
Twickenham
London

Sport, Allied Health &
Performance Sciences

31 May 2021

Dear Megan,

Re. Co-production of school-based exercise sessions to increase strength and motor control in children.

Thank you for submitting your ethics application for consideration.

I can confirm that your application has been considered by the SAHPS Ethics Committee and that ethical approval is granted. Attached you will find your signed approval form.

Yours sincerely,

Maeve Murray

Maeve Murray

Faculty of SAHPS Ethics Committee

Appendix H. Example Parental and child information and consent forms for a co-production approach to development of a school-based exercise intervention.

St Mary's University Twickenham London

Name of Participant: ____

Co-production of school-based exercise sessions to increase strength and motor control in children.

Researcher: Megan Le Warne megan.lewarne@stmarys.ac.uk

1. I agree to my child taking part in the above research. I have read the Participant Information Sheet, which is attached to this form. I understand what my child's role will be in this research, and all my questions have been answered to my satisfaction.
2. I understand that I am free to withdraw my child from the research at any time, for any reason and without prejudice.
3. I have been informed that the confidentiality of the information my child and I provides will be safeguarded.
4. I am free to ask any questions at any time before and during the study.
5. I have been provided with a copy of this form and the Participant Information Sheet.

Data Protection: I agree to the University processing personal data which my child and I have supplied. I agree to the processing of such data for any purposes connected with the Research Project as outlined to me.

Name of parent (print)…………………………………………………………………………………..

Signed……………….…………………… Date……………………………........

If you wish to withdraw your child from the research, please complete the form below and return to the main investigator named above.

I WISH TO WITHDRAW MY CHILD FROM THIS STUDY

Name of Participant: ____

Name of Parent ____

Signed: ______________________________ Date: ____________________

We would like to thank you for previously completing and returning our questionnaires about your child's physical activity and opinions on their PE lessons. We would like to invite your child to the second stage of the research project. This form provides you with all the information about the study so you can make an informed decision as to whether you and your child can participate. This research has received formal approval from the St Mary's University Twickenham Ethics Committee. All researchers have completed Disclosure and Barring Service checks.

Project details

Understanding how children would like to engage in school-based physical activity is important to developing PE sessions that children want to participate in. Our aim is to develop PE sessions with children to make sure they are adequately challenging, provide children with choice and, most importantly, are enjoyable.

This will require your child to attend group discussions at school. Group discussions will take place for 1 hour once a week for 8-weeks (between October and December) timing of sessions to be determined with the participating school. Group discussion will include some physical activity. The following page provides more information about the activities and discussions your child will take part in. Sessions will be audio recorded to allow for analysis, and these recordings will be kept in accordance with university guidelines as stated below.

Confidentiality of the data

Only the principal researcher and her research team have access to review these research records. Information collected will be stored on computers with security passwords. This data will be kept for ten years in line with St Mary's University data guidelines. You and your child will remain anonymous in any report, and no identifiable information used.

Disclaimer

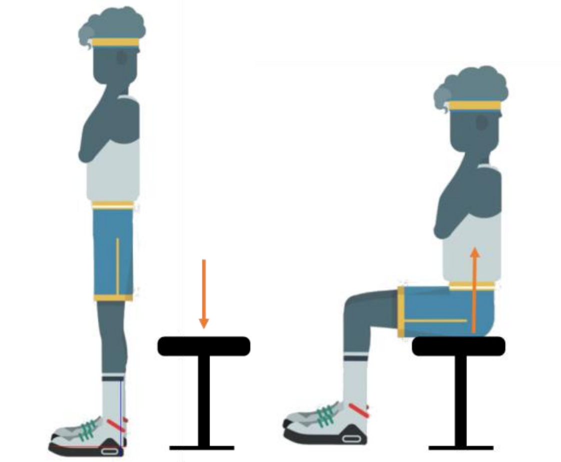
You are not obliged to participate in this study, and you are free to withdraw at any time. Should you choose to withdraw from the research, you may do so without disadvantage to yourself or your child and without any obligation to give a reason.

/eek group discussion will have a different theme and set of activities. Below is an example ıry of what may be expected each week.

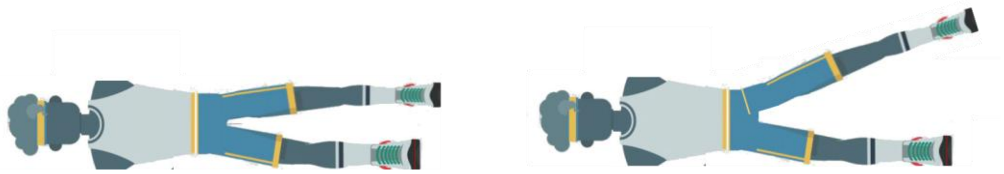
' – Introduction.
Introduction games and explaining what we will be doing in sessions.

? – Plain sessions
Children will try exercises that are designed to improve children's strength and balance. Children feedback on what they thought about them and experiment in changing them up and making them more fun. Example of exercises are

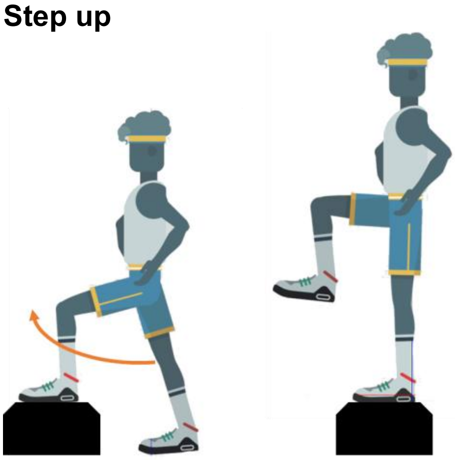
Sit to stand



Side-lying abduction

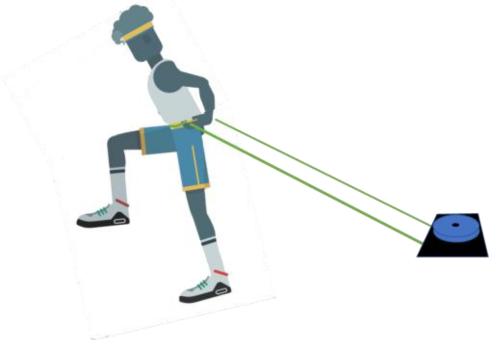


Step up



Bridge

Sled pulls



One-legged standing

– Challengingness

We discuss what happens when exercises are too hard or too easy and go back to the exercises from last week and discuss if these were easy or hard and find ways to change them.

– Having a choice and making decisions

Children experiment with different ways of giving children a choice in PE sessions, try out different ideas, and share what is more fun and enjoyable.

– Format of PE session

Children discuss how long they like sessions to be, if they prefer group, pair or solo activities and what they would choose to wear during PE sessions given a choice (e.g. barefoot/trainers, PE kit, non-school PE kit).

– Recording progress

Research Project

Hi, my name is Megan and I am collecting some information to be used in a project.

I would like to ask you and your classmates some questions about exercise and have a go at some activities.

When we chat you will be recorded so I can remember all things you tell me.
We will meet as a group once a week, if you want to stop at any point, just tell me.

It is up to you if you would like to take part. If you do, please fill in the form below.

I would like to talk to Megan for his project

Please write your name…………………………

Please return this form to your teacher as soon as possible

Appendix I. Implementation of a co-produced school-based exercise intervention to improve physical function in overweight obese 7-11 year olds.

St Mary's University Twickenham London

19 December 2022 SMEC_2017-2018_105

Megan Le Warne (SAHPS): 'Development of a best-evidence foot and lower limb intervention programme designed to improve musculoskeletal health in obese children'

Dear Megan

University Ethics Sub-Committee

Thank you for re-submitting your revised ethics application for consideration.

I can confirm that all required amendments have been made and that you therefore have ethical approval to continue with your research.

Yours sincerely

Matthew James
Chair of the Ethics Sub-Committee

Cc: Ryan Mahaffey

Appendix J. Example parent and child information and consent forms for Implementation of a co-produced school-based exercise intervention to improve physical function in overweight obese 7-11 year olds.

St Mary's University Twickenham London

We would like to invite your child to participate in a research project being undertaken as part of a Doctoral research project at St Mary's University, Twickenham. This form provides you with the information about the study so you can make an informed decision as to whether your child can participate. It also informs you of how your child's privacy will be protected and what your child's involvement will be if you agree they can take part. Your child's participation is voluntary and you can withdraw your child from the research at any time without giving any reason and this will not affect the status of your child's medical care or legal rights. To take part in the study you will be asked complete a confidential health questionnaire on behalf of your child. This research has received formal approval from the St Mary's University Twickenham Ethics Committee. All researchers have completed Disclosure and Barring Service checks.

Your participation in the research project
We are looking for boys and girls between 7 and 11 years old to take part in our study. This will consist of 3 visits to in Twickenham, and a 2-month period where children will attend exercise sessions at school aimed to increase strength and balance. Exercise sessions are fun, introduce children to activities and equipment they may not normally get to do during PE and will help develop motor skills.

Confidentiality of the Data
Information collected about your child will be stored on computers with security passwords. Only the principle researcher and his research team have access to review these research records. This data will be kept for 10 years in line with St Marys University data guidelines. Children will remain anonymous in any report and no identifiable information used.

Disclaimer
Your child is not obliged to take part in this study, and you are free to withdraw at any time during tests. Should you choose to withdraw from the programme you may do so without disadvantage to yourself or your child and without any obligation to give a reason.

Testing to be completed at St Mary's University Twickenham – this will occur 3 times, 2 months apart.

Activity Monitoring – Your child will be asked to wear an accelerometer (figure 2) for 3 consecutive days to measure how much physical activity they would usually perform. This is a small activity tracker device similar to a fitbit.

Figure 2. Accelerometers used to measure physical activity

Body Composition – Your child's height and weight will be measured, and body composition measured using a bioelectrical impedance machine. This requires your child to lay down for 5 mins. Two stickers called electrodes to will be placed on the hands and feet a small machine attaches to these by clips and the measurement is taken while your child lays still for approximately 30 seconds.

Gait Analysis - Your child will be asked to walk through the laboratory with sticky reflective markers attached to their legs and feet giving information on the movement of the limbs as the child walks, see figure 3. The small pieces of equipment attached to the skin of your child might feel a little odd for them, but it will not hurt, and they can be removed easily. Your child will be asked to wear shorts for this part of the study in order for us to see the reflective markers.

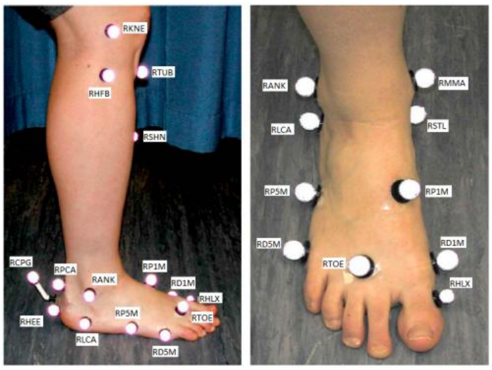


Figure 3. Showing the markers

Figure 4. Example of the dynamometer

Muscle strength testing – This will be performed on an isokinetic dynamometer, see figure 4. Your child will be asked to squeeze their leg muscles as hard as they can, this will be repeated with rest periods in between. After testing muscle strength, the child's muscles may be a little sore, similar to after playing sport, but this will disappear within 48 hours.

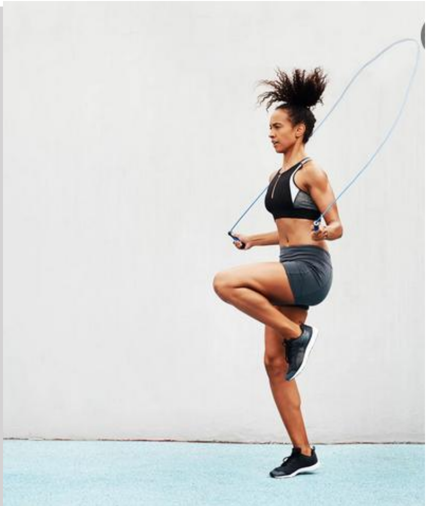
Foot pressure measurements - For this your child will be asked to stand and walk across a pressure pad barefooted.

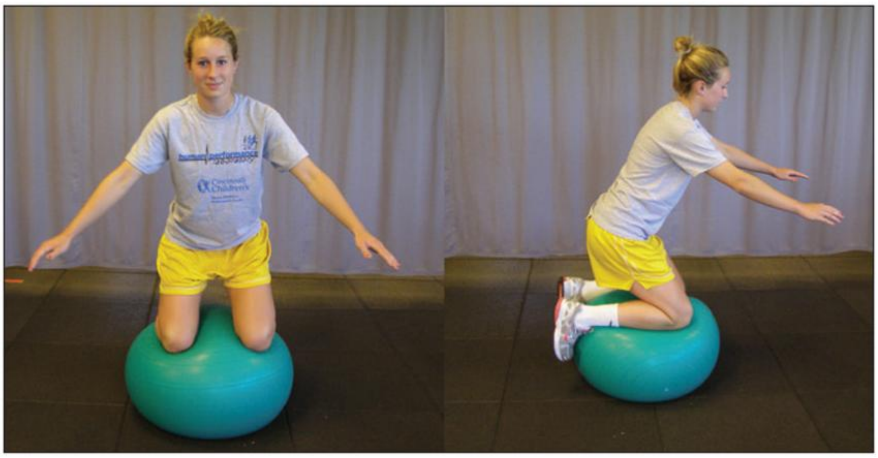
Clinical assessments - This requires your child to fill in a short questionnaire about any pain they feel whilst doing exercise and to do a number of easy functional movements such as single leg balance, getting up and sitting back down in a chair, and walking for six minutes.

Physical activity enjoyment questionnaire – This requires your child to fill in two short questionnaires about physical activity. Example questions include stating of they agree a lot, agree, neither agree or disagree, disagree, or disagree a lot to statements such as "I feel I do well", "We do activities which I also would choose myself" and "I enjoy it".

Children will be given plenty of rest throughout all testing procedures. Although highly unlikely, if at any point your child should feel ill or is injured, the exercise or test will stop immediately trained first aider will be present and parent, guardian or teacher will be notified immediately.

Exercise session – This will take place within your child's school and involve 2 weekly sessions of around 30-40 minutes. The programme is developed to safely and effectively increase strength and balance. Children will be taken through a number of body weight and resistance exercises (see example images below). All equipment will be provided. Children will be required to wear appropriate clothing and footwear such as trainers, shorts, and t-shirt.






PHAT

YOU WILL BE GIVEN A COPY OF THIS FORM TO KEEP TOGETHER WITH A COPY OF YOUR CONSENT FORM

CONFIDENTIAL VOLUNTEER MEDICAL QUESTIONNAIRE FORM

Programme title: Development of a best-evidence foot and lower limb intervention programme designed to improve musculoskeletal health in children.

Participant Name: Age: Gender:

Please give details to help us in assessing your child's possible participation in the project.
Please answer the following questions:

Does your child have condition which affects their feet (including verruca's, athletes foot, toe nail infections etc.)?	**YES / NO**
Does your child currently have a fever or feelings of being generally unwell?	**YES / NO**
Does your child have any foot, ankle or leg pain when walking?	YES / NO
Has your child had surgery or Chronic Illnesses? (some examples of chronic conditions include, but are not limited to): Asthma, Diabetes, Cerebral palsy, Epilepsy, Congenital heart problems	YES / NO
Has your child had any foot, ankle or leg injuries?	YES / NO
Has your child had any allergies?	YES / NO
Does your child have a pacemaker or implantable cardioverter defibrillators (ICD)	YES / NO
Is there any other reason why your child should not participate in this study?	YES / NO

Which is your child's dominant foot (i.e. kicking Foot) Right / Left (please circle)

Name of Participant	Date	Signature (parent)
……………………………..	……………………………..	……………………………..
Name of Researcher	Date	Signature
……………………………..	……………………………..	……………………………..

Research Project

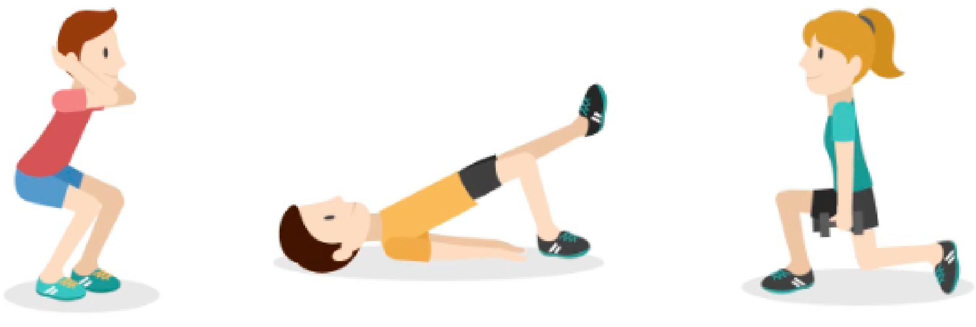
Hi, my name is Megan and I am collecting some information to be used in a project.

This piece of research is tying to find out if we can change how some boys and girls walk.

We would like to measure -

- How strong you are and how you walk.
- Measure your height, weight and the size of your feet
- Ask you to walk for 6 minutes and time you getting up from a chair.
- And wear an activity monitor to see how much you move day to day.

And we would also like to take you and your class through some exercises like below. This will take place in your school over several weeks.



This will happen over several weeks, and if you want to stop at any time then just tell me.