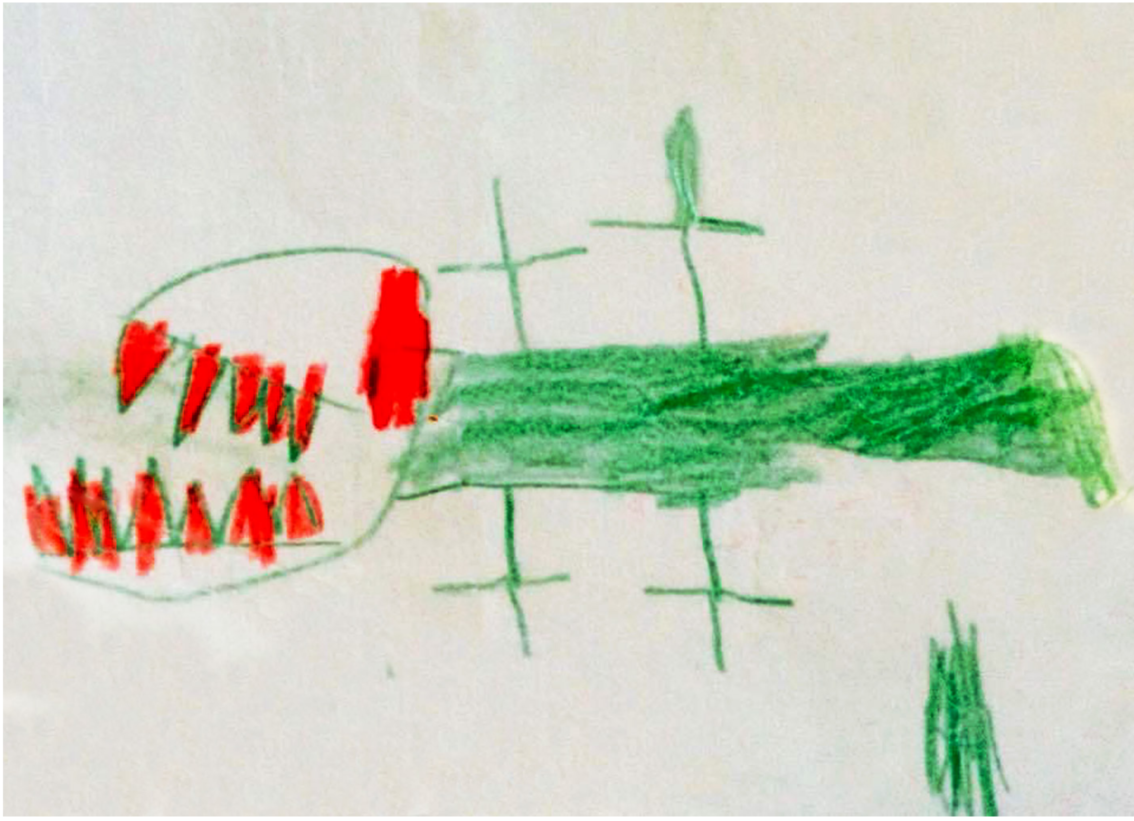
JYU DISSERTATIONS 521

Sari Slotte

Fundamental movement skills, cardiorespiratory and muscular fitness in association with adiposity in eight-year-old children



UNIVERSITY OF JYVÄSKYLÄ
FACULTY OF SPORT AND HEALTH SCIENCES

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ABSTRACT

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In this dissertation, the associations between fundamental movement skills (FMS), cardiorespiratory fitness (CRF), and muscular fitness (MF) with dual-energy X-ray absorptiometry (DXA)-assessed total body adiposity and abdominal adiposity and body mass index (BMI)-defined weight status in children were examined. Study I was a systematic review, with data gathered from 12 cross-sectional studies that examined associations of FMS and weight status in 3- to 12-year-olds. For Studies II, III, and IV (which use a cross-sectional population-based approach), data were gathered from 304 eight-year-old Finnish children (151 girls and 153 boys) who participated in a study at the UKK Institute – Centre for Health Promotion Research in Tampere, Finland. Children's FMS were assessed with the Test of Gross Motor Development 2, CRF with the 20 meter shuttle run test, and MF with three tests from the FitnessGram battery. Total body adiposity and abdominal adiposity were assessed with DXA. In addition, weight, height, and waist circumference (WC) were measured, while International Obesity Task Force BMI cut-off points were used to categorize children's weight as healthy, overweight, or obese. Based on the findings of the systematic review (Study I), there was an inverse but weak association between FMS and weight status. Several assessment methods were used to define FMS, while weight status was mainly established using BMI. The key findings from Studies II, III, and IV revealed that DXA-measured total body adiposity and abdominal adiposity were significantly inversely associated with FMS, CRF, and MF among eight-year-old children. Lower total body adiposity and abdominal adiposity were associated with higher proficiency in FMS. In addition, overweight or obese children with higher levels of CRF or MF had significantly lower total and abdominal adiposity than children in the same BMI category with lower CRF or MF. These inverse associations were also seen among healthy weight children. The results of the present study indicate that children should be encouraged to practice the entire range of FMS, with special attention paid to ensuring that overweight and obese children learn FMS. Further, overweight and obese children with lower levels of CRF or MF should be motivated to engage in activities to enhance those two areas of health-related fitness. The findings highlight the importance of FMS, CRF and MF in children and should be taken into account in teacher education programs and in physical education curricula for primary schools. The insights obtained in this study can also be used to develop more detailed recommendations for obesity prevention and health promotion among school-age children.

Keywords: fundamental movement skills, cardiorespiratory fitness, muscular fitness, abdominal adiposity, adiposity, healthy weight, overweight, obesity, body mass index, BMI, DXA, body composition

TIIVISTELMÄ (ABSTRACT IN FINNISH)

Slotte, Sari
Motoristen perustaitojen, hengitys- ja verenkiertoelimistön kunnon sekä lihaskunnon yhteydet lihavuuteen kahdeksanvuotiailla lapsilla
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Tässä neljän osatutkimuksen tutkimuskokonaisuudessa selvitettiin motoristen perustaitojen, hengitys- ja verenkiertoelimistön kunnon sekä lihaskunnon yhteyksiä painoindeksiin (BMI) ja kaksienergiaisella röntgenabsorptiometrialla (DXA) -arvioituun koko kehon rasvaan ja vatsan alueen rasvaan lapsilla. Osatutkimuksen I tiedot kerättiin 12 erilaisesta poikkileikkaustutkimuksesta, missä tarkasteltiin 3–12-vuotiaiden lasten motoristen perustaitojen ja painon yhteyttä. Osatutkimuksissa II, III ja IV kerättiin tiedot 304 kahdeksanvuotiaasta suomalaislapsesta (151 tyttöä ja 153 poikaa), jotka osallistuivat tutkimukseen UKK-instituutissa, terveyden edistämisen tutkimuskeskuksessa Tampereella. Lasten motoriset perustaidot arvioitiin Test of Gross Motor Development-2 -testillä, hengitys- ja verenkiertoelimistön kunto 20 metrin sukkulajuoksutestillä ja lihaskunto kolmella FitnessGram-testistön testillä. Koko kehon rasvan määrä ja vatsan alueen rasvan määrä mitattiin DXA'lla. Paino, pituus ja vyötärönympärys mitattiin ja IOTF'n BMI raja-arvoja käytettiin lasten painon (terve paino, ylipaino ja lihavuus) määrittämiseen. Systemaattisen katsauksen (tutkimus I) tulosten perusteella motoristen perustaitojen ja painoluokan välillä oli käänteinen heikko yhteys. Motoristen perustaitojen arviointimenetelmät olivat vaihtelevat ja paino arvioitu pääosin käyttäen painoindeksiä. Päätuloksina II, III ja IV tutkimuksista huomattiin, että tarkasti DXA-menetelmällä mitatut koko kehon ja vatsan alueen rasvan määrä ovat käänteisesti yhteydessä kahdeksanvuotiaiden lasten motorisiin perustaitoihin, hengitys- ja verenkiertoelimistön kuntoon ja lihaskuntoon. Pienempi koko kehon ja vatsan alueen rasvan määrä oli yhteydessä parempiin motorisiin perustaitoihin. Lisäksi ylipainoisilla tai lihavilla lapsilla, joilla oli parempi hengitys- ja verenkiertoelimistön kunto tai lihaskunto, oli merkittävästi pienempi koko kehon ja vatsan alueen rasvan määrä, kuin ylipainoisilla tai lihavilla lapsilla, joilla oli heikompi hengitys- ja verenkiertoelimistön kunto tai lihaskunto. Tämä yhteys nähtiin myös tervepainoisten lasten joukossa. Tässä väitöstutkimuksessa saadut tulokset osoittavat, että lapsia tulisi rohkaista harjoittelemaan monipuolisesti motorisia perustaitoja ja erityistä huomiota tulisi kiinnittää ylipainoisten ja lihavien lasten motoristen perustaitojen oppimiseen. Lisäksi ylipainoisia ja lihavia lapsia, joilla on heikompi hengitys- ja verenkiertoelimistön kunto tai lihaskunto, tulisi motivoida osallistumaan hengitys- ja verenkiertoelimistön kuntoa ja lihaskuntoa kehittävään liikuntaan. Tulokset korostavat motoristen perustaitojen ja terveyskunnon merkitystä lapsilla, mikä tulisi ottaa huomioon peruskoulun liikuntakasvatuksessa ja opettajankoulutuksessa. Näitä tietoja voidaan käyttää myös laadittaessa kouluikäisten lasten lihavuuden ehkäisyn ja terveyden edistämisen ohjeita ja suosituksia.

Asiasanat: motoriset perustaidot, hengitys- ja verenkiertoelimistön kunto, lihaskunto, terve paino, ylipaino, lihavuus, vyötärölihavuus, painoindeksi, BMI, DXA, kehon koostumus

Author Sari Slotte, MSc
Faculty of Sport and Health Sciences
University of Jyväskylä
Finland
Email sari.a.slotte@jyu.fi
ORCID 0000-0002-5283-6040

Supervisors Professor emeritus Pauli Rintala, PhD
Faculty of Sport and Health Sciences
University of Jyväskylä
Finland

Adjunct professor Katriina Kukkonen-Harjula, MD, PhD
Faculty of Medicine and Health Technology
Tampere University
Finland

Reviewers Professor Anthony D. Okely, PhD
School of Health and Society
University of Wollongong
Australia

Professor emeritus Jeffrey A. McCubbin, PhD
College of Health and Human Sciences
Colorado State University
United States of America

Opponent Adjunct professor Katja Borodulin, PhD
Age Institute
Finland

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This project started a long time ago... I had been working few years as a health and physical education teacher when we decided with my husband Janne to take some time off from work. We went on a backpacking trip for a year, and during that year my thoughts became clearer that I want to do research work. And here I am finally, sitting with a blank page in front of me, with the intention of doing the last task of this dissertation – to write the acknowledgements. This is now the light moment when I can stop for a while and look back. This dissertation work has been with me for a long time in my life – life which has been quite a winding path with some obstacles. When I started, I did not know it would take this long to finish this project, but it was good that I did not know it. Over these years I have not only learned how to become a researcher, but also, I have learned a lot about myself and the life. Today the main feeling is gratitude towards everyone who in some way participated in this study and who have walked with me during these years. I also feel longing because many of my loved ones are no longer here. My parents, my dear godmother Assa and my beloved, late husband Janne – with whom I would have wanted to share this moment. But I know that bubbling feeling of happiness will surely come later, when I really understand that I have finally reached the end of this project, and when we get together to celebrate with the people who matter to me.

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In Helsinki 20.10.2022
Sari

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following original publications, which will be referred to in the text by their Roman numerals (I–IV).

I Slotte S, Sääkslahti A, Kukkonen-Harjula K & Rintala P. Fundamental movement skills and weight status in children: A systematic review. *Baltic Journal of Health and Physical Activity. 2017;9*(2), 115-127.
DOI: https://doi.org/10.29359/bjhpa.09.2.11

II Slotte S, Sääkslahti A, Metsämuuronen J & Rintala P. Fundamental movement skill proficiency and body composition measured by dual energy X-ray absorptiometry in eight-year-old children. *Early Child Development and Care. 2015;185*(3), 475-485.
DOI: https://doi.org/10.1080/03004430.2014.936428

III Stigman S (Slotte S), Rintala P, Kukkonen-Harjula K, Kujala U, Rinne M & Fogelholm M. Eight-year-old children with high cardiorespiratory fitness have lower overall and abdominal fatness. *International Journal of Pediatric Obesity. 2009;4*(2), 98-105.
DOI: https://doi.org/10.1080/17477160802221101

IV Slotte S, Kukkonen-Harjula K, Rinne M, Valtonen J & Rintala P. Associations of muscular fitness and body composition in children. *Early Child Development and Care. 2021* Oct 8.
DOI: https://doi.org/10.1080/03004430.2021.1982928

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ABBREVIATIONS

AF	abdominal fat
ANOVA	analysis of variance
BF	total body fat
BMI	body mass index
CRF	cardiorespiratory fitness
CVD	cardiovascular disease
DOI	digital object identifier
DXA	dual energy X-ray absorptiometry
FFM	fat-free mass
FMS	fundamental movement skills
HRF	health-related fitness
IOTF	International Obesity Task Force
M	mean
MF	muscular fitness
p, p -value	significance probability
PA	physical activity
SD	standard deviation
SPSS	Statistical Package for the Social Sciences
WC	waist circumference
WHO	World Health Organization

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ORIGINAL PAPERS

1 INTRODUCTION

Over the past decades, the prevalence of childhood overweight and obesity dramatically increased in most regions and countries worldwide (Ng et al. 2014; NCD-RisC 2017; Di Cesare et al. 2019). Even if the rise plateaued in most European countries (Garrido-Miguel et al. 2019) and in high-income countries globally (NCD-RisC 2017) just before the COVID-19 pandemic, the COVID-19 lockdowns caused significant increases in body weight and body mass index (BMI), as well as the increase of overweight and obesity prevalence among school-age children, as the recent systematic research and meta-analyses clearly demonstrate (Chang et al. 2021; La Fauci et al. 2022). Because the treatment of obesity is relatively challenging and obesity during childhood have both short-term and long-term negative health consequences, the prevention of overweight and obesity needs to be a high priority as early as possible in children's lives (Di Cesare et al. 2019).

Obesity is the outcome of energy imbalance where biological, environmental, and behavioral factors contribute (WHO 2016) and the main modifiable behavioral drivers to the development of childhood obesity are thought to be diet, physical activity (PA), and sleep (Swinburn et al. 2011). As recent international studies have shown, at the same time while childhood overweight and obesity have increased, the fundamental movement skills (FMS) and the physical fitness of primary school aged children have decreased (NCD-RisC 2017; Aubert et al. 2018; Bolger et al. 2021; Fühner et al. 2021). This is a worrying trend, as both weight status and physical fitness are linked to health (Ortega et al. 2008; Ortega et al. 2018a; Di Cesare et al. 2019). The potential of physical fitness to attenuate the negative consequences of obesity has been of interest to researchers (Ortega et al. 2018a) and studies have shown that cardiorespiratory fitness (CRF) is a strong indicator of health and associated with certain health outcomes, such as obesity and abdominal obesity in youth (Ortega et al. 2018a; Raghuveer et al. 2020). While muscular fitness (MF) is also known to be important marker of health, less is still known about the associations between MF and obesity in childhood, and most of the data available from previous studies are based on BMI-defined weight status (Smith et al. 2014; Thivel et al. 2016). In addition to health-related fitness (HRF), there has also been increasing interest in the impact of FMS on health outcomes, among the researchers in the field of exercise science (Lubans et al. 2010). While the early childhood years, before middle childhood, is a time period of rapid growth and a critical period for the development of overweight and obesity, it is an important time for the development of FMS (Rolland-Cachera et al. 1984; Goodway et al. 2019; Arisaka et al. 2020). FMS are thought to be a key factor in the promotion of a physically active lifestyle, which in turn may lead to positive health outcomes such as higher levels of HRF and healthier weight status (Stodden et al. 2008; Lubans et al. 2010; Robinson et al. 2015; Barnett et al. 2021; Barnett et al. 2022). To date, the studies of the association between FMS and overweight and obesity in middle childhood age children are still scarce, in which total body and abdominal adiposity are assessed using more sophisticated techniques (Stodden et al. 2008; Lubans et al. 2010; Robinson et al. 2015; Barnett et al. 2022).

The prevention of childhood obesity and the improvement of HRF have both great impacts on public health (Chaput et al. 2020) and gaining more information about the association between FMS, HRF and adiposity in childhood, is important in the prevention of overweight and obesity and the promotion of children's overall health and well-being. To obtain more precise knowledge, there is a need for studies using more accurate methods than solely BMI for assessing adiposity. BMI is a proxy measure and does not distinguish between fat mass and non-fat mass (Marra et al. 2019), while dual energy X-ray absorptiometry (DXA) is one of the more accurate and applicable methods for assessing body composition in pediatric populations (Cossio Bolaños et al. 2019) and often used as a gold standard or reference method to validate indirect anthropometric measures (Orsso et al. 2020). DXA was selected to measure total body and abdominal adiposity in the present study, for providing more accurate estimates of body composition (Marra et al. 2019). International BMI references (Cole at al. 2000) for defining weight status, along with widely employed field tests for FMS, CRF, and MF were used to obtain internationally comparable information (Ulrich 2000; Meredith & Welk 2010).

This dissertation takes part in the international research discourse related to childhood overweight and obesity, examining the associations of FMS, CRF, and MF with total body and abdominal adiposity in population-based cross-sectional sample of eight-year-old Finnish children. The insights obtained in this study can be taken into account in teacher education and in physical education curricula for primary schools, and also be used to develop more detailed recommendations for obesity prevention and health promotion among school-age children.

2 LITERATURE REVIEW

The overall purpose of this doctoral study was to examine the associations of FMS, CRF, and MF with total body and abdominal adiposity and BMI-defined weight status in children. The research literature related to these topics is reviewed in the following sections.

2.1 Childhood overweight and obesity

Overweight and obesity as defined by BMI, have increased worldwide in children and adolescents of all ages over the past four decades (Ng et al. 2014; NCD-RisC 2017). In addition, obesity appears to have increased more rapidly in school-age children than in younger children (Di Cesare et al. 2019). In Finland, 29% of boys and 18% of girls aged 7–12 were estimated to be overweight or obese in 2018, based on Finnish ISO-BMI (National Institute for Health Welfare 2019). In addition, studies have shown that children's waist circumference (WC) has increased even more than body mass index (BMI) over time (McCarthy et al. 2001; Okosun et al. 2006; Garnett et al. 2011; Hassapidou et al. 2017), even if comprehensive global statistics on abdominal adiposity are not available.

There is strong evidence that overweight and obesity during childhood have both short-term and long-term negative health consequences (Di Cesare et al. 2019). In addition, childhood overweight and obesity are likely to continue into adulthood (Singh et al. 2008), which increases the risk of developing cardiovascular disease, type 2 diabetes, certain cancers, and musculoskeletal disorders later in life (Di Cesare et al. 2019). Abdominal adiposity in particular has been shown to be more closely associated with health risks than total body adiposity (Savva et al. 2000; Kelishadi et al. 2015; Jin et al. 2020). Because of these established health risks and substantial increases in prevalence, childhood obesity is a significant and growing global problem (Ng et al. 2013; WHO 2016; GBD 2015 Obesity Collaborators 2017; NCD-RisC 2017; Garrido-Miguel et al. 2019; Chang et al. 2021; La Fauci et al. 2022). Concern about the health risks associated with obesity has become nearly universal and the World Health Organization (WHO 2016) has set a goal to halt the increase in childhood obesity by 2025. Unfortunately, unlike other major global risks, there has been little evidence of successful population-level intervention strategies to curb childhood obesity (Ng et al. 2013); indeed, the BMI of children and adolescents was reported to have increased significantly during the COVID-19 pandemic (Chang et al. 2021; Woolford et al. 2021; La Fauci et al. 2022; Shalitin et al. 2022).

A number of factors – biological, environmental, and behavioral – contribute to the development of childhood obesity (WHO 2016). Obesity is the outcome of energy imbalance, and its main modifiable behavioral drivers are diet, PA, and sleep (Swinburn et al. 2011). The strong persistence of overweight and obesity, the difficulty of treating them, and the short- and long-term negative health consequences, all highlight the need to prevent overweight and obesity at the earliest possible stage of life (Singh et al. 2008; Pandita et al. 2016; Lee & Yoon 2018).

2.1.1 Definition of obesity

Obesity has been defined as an accumulation of excess body fat to the extent that it may have an adverse effect on health (WHO 2000; World Obesity Federation 2021). The primary purposes for defining obesity in children are to predict health risks and provide comparisons between studies (Rolland-Cachera 2011; Cole & Lobstein 2012. Any effort to define obesity consists of choosing a suitable measure of adiposity and using appropriate overweight and obesity cut-offs that are based on relative health risks (Rolland-Cachera 2011; Cole & Lobstein 2012). In addition, it is not only the amount but also the distribution of adiposity that is important, since increased health risks have been associated with excess adipose tissue in the abdominal region of children (Karlsson et al. 2013; Kjellberg et al. 2019). It has been suggested that an ideal measure of adiposity should be accurate, precise, easy to obtain, and widely accepted, with well-documented, published reference values, but no existing single measurement tool meets all these criteria (Power et al. 1997; Lobstein et al. 2004; Lobstein 2017).

2.1.2 Methods for assessing adiposity

Several methods have been developed – both direct laboratory and indirect field techniques – for assessing adiposity (Lobstein et al. 2004; Orsso et al. 2020). Direct laboratory measurement techniques of body composition provide an accurate estimation of total body adiposity and abdominal adiposity, and various components of fat-free mass (FFM) (Lobstein et al. 2004; Lee & Gallagher 2008; Lemos & Gallagher 2017; Orsso et al. 2020). Several direct measurement techniques exist (Table 1) but they require special equipment and qualified personnel and are thus mainly used in clinical research settings. Of these sophisticated direct measures, DXA is preferred; it is one of the most accurate and applicable methods for assessing body composition in pediatric populations (Cossio Bolaños et al. 2019) and is often used as a gold standard or reference method to validate indirect anthropometric measures (Orsso et al. 2020).

Indirect field assessment methods (Table 1) are less accurate but easier and less expensive to use than laboratory techniques; thus, they are mainly used in large-scale population surveys and clinical and public health screening. Examples of indirect field methods are bioelectrical impedance analysis and several anthropometric measurements, such as height, weight, skinfold thickness and waist, hip, and other circumference measurements (Lobstein et al. 2004).

While anthropometric field assessments have been widely used, a recent systematic review summarizing the evidence on the reliability and validity of techniques to assess body composition concluded that it is not possible to accurately assess body composition using anthropometric measurements, and laboratory techniques cannot be replaced by field methods in cross-sectional and longitudinal analyses of the pediatric overweight and obese population (Orsso et al. 2020). Further detailed descriptions and discussions of the relative advantages and disadvantages of the various measure techniques can be found in the literature (Lobstein et al. 2004; Lee & Gallagher 2008; Lemos & Gallagher 2017; Orsso et al. 2020).

TABLE 1 Methods for assessing adiposity (Lobstein et al. 2004 modified)

Direct laboratory methods

- Air displacement plethysmography
- Computer tomography (CT)
- Dual-energy X-ray absorptiometry (DXA)
- Isotope dilution
- Magnetic resonance imaging (MRI)
- Three-compartment model
- Underwater weighing (hydro-densitometry)

Indirect field methods

- Anthropometric measures
    - Body mass index (BMI, weight/height^2)
    - Skinfold thickness
    - Waist circumference (WC)
    - Waist-to-hip ratio (WHR)
    - Weight
    - Weight-for-height (weight as a percentage of the expected or median weight for the child's sex and height)
- Bioelectrical impedance analysis (BIA)

2.1.3 Weight status

The definition of weight status is generally based on anthropometric measures and estimation of relative adiposity, instead of the direct laboratory measures, because of the easier measurement techniques. In adults, BMI, which is defined as weight in kilograms divided by height in meters squared, is the most widely used indicator for defining weight status; underweight, healthy weight, overweight and obesity (WHO 2000). Overweight is generally defined as a BMI greater than 25 kg/m^2 (25–30 kg/m^2) and obesity greater than 30 kg/m^2; these cut-off points intend to be related to possible health risks (WHO 2000).

Although BMI is only a proxy measure of adiposity, it remains the most widely used measure, both clinically and in population studies, even in children (Lobstein et al. 2004). In childhood, BMI varies considerably with age, because of the rapid growth, so a child's BMI has to be compared with the BMI of a reference population of children of the same sex and age (Cole et al 2000; de Onis et al. 2007). Currently there is no universal standard system for using BMI to define overweight and obesity in children; instead, different national and international references and cut-offs are used (Rolland-Cachera 2011; Cole & Lobstein 2012), and controversy exists, whether a national or international and which reference standard should be used (Lobstein 2017).

The WHO (de Onis et al. 2007) and International Obesity Task Force (IOTF) (Cole et al. 2000; 2007) references are the two international standards most often used to assess childhood weight status, which is divided into underweight, healthy weight, overweight, obesity, and severe obesity (Cole et al. 2000; Cole et al. 2007; Cole & Lobstein 2012; de Onis et al. 2007; Rolland-Cachera 2011). It should be noted that these two international references have different age-specific cut-offs and can therefore give different weight status estimates for the same data. Previous studies have reported differences in prevalence estimations regarding the different definitions, finding a higher prevalence of overweight and obesity using the WHO reference when compared with results from the IOTF reference (Gonzalez-Casanova et al. 2013; Kêkê et al. 2015; Pérez et al. 2020). Ideally, a common definition of childhood obesity should be adopted, but in the absence of such a consensus, the recommendation is to report prevalence using both the WHO and IOTF references (Rolland-Cachera 2011; Cole & Lobstein 2012).

The IOTF childhood BMI cut-offs (Cole et al. 2000) are based on and linked to the corresponding adult BMI cut-offs of 25 kg/m^2 for overweight, and 30 kg/m^2 for obesity. In 2007, equivalent cut-off values for underweight were published (Cole et al. 2007) and in 2012 a definition of severe obesity (a BMI of 35 kg/m$^{2)}$ was added (Cole & Lobstein 2012). The IOTF dataset features cohorts from six countries and it was created and is recommended to provide internationally comparable data between different studies in the childhood overweight and obesity research (Cole et al. 2000). The widely used IOTF reference is also generally recommended by the World Obesity Federation (worldobesity.org).

While BMI is widely used as a proxy measure to estimate adiposity, it is not without limitations. Because BMI is based only on height and weight, it does not distinguish between fat mass and FFM and does not give information about body fat distribution; therefore, it is not alone an adequate criterion to evaluate the health status (Bala et al. 2016; Genovesi et al. 2020; April-Sanders & Rodriguez 2021). Proxy measures of abdominal adiposity, such as WC may be better predictor of cardiovascular disease (CVD) risk, being stronger than, and independent of BMI (Browning et al. 2010; Xi et al. 2020). At present, there is no national Finnish WC reference available for children and adolescents, but the first international WC cut-offs for defining abdominal obesity in children and adolescents aged 6 to 18 were recently developed and proposed (Xi et al. 2020).

2.2 Motor development and fundamental movement skills

Due to differences and varying practices in movement skill research, the various definitions adopted, and the terms and perspectives used are described in the following subsections. In a systematic review of terminology and recommendations for the research which terms to use, the terms "fundamental movement skills" and "fundamental motor skills" were both used, but the former appeared more frequently (Logan et al. 2018). In this dissertation the term "fundamental movement skills" is used.

2.2.1 Motor development

The history of motor development research is diverse and has emphasized different explanations of the process of motor development and movement behavior (Logan et al. 2018; Goodway et al. 2019; Clark et al. 2020). Furthermore, different theories and different definitions exist, and a variety of terms have been used over the years in the motor development and of motor behavior literature (Logan et al. 2018).

Motor development is a complex and continuous lifelong process of learning how to move in response to everyday situations in changing environment, with maturation and experience playing key roles (Goodway et al. 2019). The developmental differences in movement behavior can be seen and studied through observation of changes in process (form) or product (outcome). In addition, in the contemporary literature the terms "motor skill" and "movement skill" are often used interchangeably, but there is a minor difference in emphasis. Motor skill emphasizes what the underlying mechanisms are, e.g., neural, biomechanical, or perceptual, while movement skill emphasizes what can be seen through observation (Goodway et al. 2019). Observable movement may be grouped according to purpose into three functional categories and across all the phases of motor development: stabilizing, locomotor, and manipulative movement tasks or a combination of the three (Goodway et al. 2019).

2.2.2 Fundamental movement skills

Early childhood to middle childhood is regarded as a critical time for the development of FMS (Goodway et al. 2019), which are the foundation and prerequisite for the more complex, specialized movement skills required in everyday life and a wide range of physical activities in both childhood and later in life (Goodway et al. 2019). FMS are basic movement skills that progress through a definite, observable process from immaturity to proficiency and should be developed during the early childhood years. FMS progress from the initial to emerging and finally to proficient stages and are greatly influenced by a child's opportunities for practice, encouragement, and instruction in a positive and nurturing learning environment (Goodway et al. 2019). FMS are generally classified as locomotor skills and object control or manipulative skills (Goodway et al. 2019). Locomotor skills consist of FMS that allow the child to navigate through space or move from one point to another, such as running, hopping, jumping, sliding, galloping, and leaping. Object control/manipulative skills consist of FMS that involve manipulating or controlling objects, such as striking, dribbling, kicking, throwing, rolling, and catching (Goodway et al. 2019).

FMS do not develop naturally or automatically over time, rather, it has been found that children who are exposed to developmentally and instructionally appropriate planned FMS activities appear to have greater increases in FMS than those who engage only in free play (Deli et al. 2006; Robinson & Goodway 2009; Logan et al. 2012). FMS need to be taught and reinforced; with appropriate encouragement, instructions, and opportunities for learning and practice, children have the developmental potential to reach the proficient stage of FMS (Morgan et al. 2013; Goodway et al. 2019; Brian et al. 2020). Depending on the skill, children may have potential to reach the proficient FMS stage by six to ten years of age. Typically, children are at the initial or emerging stages of FMS development at ages six to seven (Goodway et al. 2019), which is when they enter school in Finland.

2.2.3 Assessment of fundamental movement skills

Children's FMS development can be seen through both product (outcome) and process (form) perspectives and FMS competence can be evaluated by product or process characteristics of movement using product-oriented tests or process-oriented tests (Logan et al. 2018; Goodway et al. 2019). Product-based measures of FMS are typically quantitative and focus on the end product or outcome of the movement, such as time, speed, or distance. Process-based measures of FMS are typically qualitative and examine the pattern of movement, such as form, style, or mechanics (Logan et al. 2012; Goodway et al. 2019).

There are several tests to measure FMS, and selecting the appropriate test depends on many factors (Cools et al. 2009; Griffiths et al. 2018). Recent years have been a shift in emphasis from the product-oriented tests to the process-oriented tests of FMS, which may be due to the lack of standardized, product-oriented assessments for all FMS (Logan et al. 2018). In addition, process-oriented tests assess how children move, provide qualitative information on the characteristics or quality of movement patterns, and give researchers the opportunity to identify the developmental skill level of the child (Hardy et al. 2010; Goodway et al. 2019). On the contrary, when using quantitative product-based measures, physical growth or maturational status may affect the result. In addition, process-oriented assessments can be studied with video recording so that skills performed at high speeds can be reviewed in slow-motion playback, which offers more precision in analysis because the video can be replayed as often as is necessary.

In Logan and colleagues' (2018) review, the majority of studies measured FMS with a process-oriented measure, with the Test of Gross Motor Development being the most common choice (first edition, Ulrich 1985; second edition, Ulrich 2000). At the present there also exists the third edition of the TGMD (Ulrich 2019). The TGMD is a process-oriented assessment that is designed to assess FMS in children aged 3 to 10 (Ulrich 1985; Ulrich 2000; Ulrich 2019). The assessment includes a selection of locomotor and object-control skills (TGMD-1 and TGMD-2) or ball skills (TGMD-3) that represent the FMS that are commonly taught in primary school physical education curricula on an international scale (Ulrich 1985; Ulrich 2000; Ulrich 2019).

2.2.4 Fundamental movement skills and weight status

In recent years there has been increasing interest in the impact of FMS on health outcomes. FMS are thought to be a key factor in the promotion of a physically active lifestyle, which in turn may lead to positive health outcomes such as healthy weight status (Stodden et al. 2008; Lubans et al. 2010; Robinson et al. 2015; Barnett et al. 2021). It has been hypothesized that there is a reciprocal relationship between FMS and weight status that is synergistically influenced by physical activity (PA), health-related fitness (HRF), and perceived competence, leading to a variety of individual trajectories across developmental time (Stodden et al. 2008; Barnett et al. 2022). FMS may be considered both precursors and a consequences of weight status in childhood. However, it remains unclear whether low FMS competence leads to unhealthier weight status, or if unhealthy weight status negatively influences FMS competence over time. Several cross-sectional (Okely et al. 2004; Lubans et al. 2010; Logan et al. 2011) and longitudinal (Barnett et al. 2022) studies of children and adolescents have shown that there may be an inverse association between FMS and adiposity, as measured by a variety of FMS and adiposity assessments. By contrast, one systematic review and meta-analysis (Barnett et al. 2016) concluded that higher BMI was not correlated with FMS (specifically, object control skill competency), while an indeterminate association was found for locomotor skills. This inconsistency of results may be due to the different measures and definitions of FMS used in previous research. Research on FMS development and performance in middle childhood is rather dispersed; measurement of FMS needs more standardized methods to allow for effective comparisons of results between studies. In addition, the association between FMS and adiposity has been assessed only by BMI in most studies. Studies on children that relies on accurate measures of body composition are scarce (Stodden et al. 2008; Lubans et al. 2010; Robinson et al. 2015; Barnett et al. 2022).

2.3 Health-related fitness

Physical fitness refers to a set of attributes that people have or can achieve (Caspersen et al. 1985) and can be described in terms of skill-related fitness and health-related fitness (HRF). The former is associated with motor skill performance or sport and includes speed, agility, balance, coordination, power, and reaction time. HRF consists of those components of physical fitness that have a connection with health; its components are commonly defined as CRF, MF, flexibility, and body composition (Caspersen et al. 1985; Goodway et al. 2019). Because body composition is not a performance measure and because it is common in health promotion research for body composition to be positioned as an outcome of the relationships between HRF and other variables, some question its inclusion as a component of HRF (The President's Council on Physical Fitness and Sports 2012; Britton et al. 2019).

Assessing physical fitness has been suggested to be a reliable way to monitor health in children and adolescents (Ortega et al 2008). There are several field-test batteries available to test children's and adolescents' physical fitness levels and the common internationally used test batteries are the FitnessGram, EUROFIT and, most recently, ALPHA health-related fitness test battery. These tests are considered to be valid, simple, precise, and low-cost health monitoring tools (Ruiz et al. 2011; Marques et al. 2021).

2.3.1 Cardiorespiratory fitness

Of the HRF components, CRF has been studied the most and there is strong evidence that it is, even at young ages, an important indicator of both current health (Ortega et al. 2008; Raghuveer et al. 2020) and future health (Ruiz et al. 2009a), also independent of PA (Ekelund et al. 2007). CRF, which is also known as cardiovascular fitness, cardiorespiratory endurance, aerobic fitness, and aerobic capacity, refers to the capacity of the body’s circulatory and respiratory systems to supply oxygen to the skeletal muscles needed during PA (Caspersen et al. 1985; Ross et al. 2016). At any given baseline level, CRF can increase or decrease depending on one’s ability to be physically active. PA-induced improvements in CRF may be explained by structural and functional adaptations leading to a better oxygen transport system (Raghuveer et al. 2020). CRF represents both an individual’s past PA and the ability to be physically active (Caspersen et al. 1985; Raghuveer et al. 2020) and may be a more predictive measure of health outcomes in children than PA (Ross et al. 2016; Raghuveer et al. 2020).

In recent decades, children’s CRF has declined worldwide, and that decrease has generally been larger among boys than girls (Tomkinson & Olds 2007; Tomkinson et al. 2019a). Although the reasons for this decline are not well understood, an increase in obesity, more sedentary time, and decreased levels of moderate-to-vigorous PA may each have contributed (Tomkinson & Olds 2007; Tomkinson et al. 2019a).

2.3.1.1 Assessment of cardiorespiratory fitness

The importance of assessing CRF has been highlighted in scientific statements (Ross et al. 2016; Raghuveer et al. 2020), as CRF is an objective measure of health that can be tracked over time and compared across populations (Ross et al. 2016; Tomkinson et al. 2019 b; Raghuveer et al. 2020). In addition, CRF is superior to assessments of PA, and it has been proposed, that measuring CRF should be included in health screening in children (Raghuveer et al. 2020).

CRF can be measured or estimated using laboratory tests or field-based tests and using a variety of protocols. The most widely used indicator of CRF is the volume of oxygen that is consumed at maximal physical exertion (VO_{2max}). Laboratory tests, such as running or cycling tests that progress to exhaustion, require maximal effort and are thus referred to as maximal exercise tests, are objective and accurate measures of CRF. These maximal exercise tests usually measure cardiorespiratory parameters such as inspiratory and expiratory gases, blood pressure, heart rate, and the heart's electric activity (Hamlin et al. 2014; Raghuveer et al. 2020). Although directly measured peak oxygen uptake is the criterion measure of children's CRF (Armstrong et al. 2011), it is not practical for mass testing because of high cost, the medical and technical expertise required, the sophisticated equipment used, and time constraints (Silva et al. 2018).

Properly conducted field-based CRF tests offer a simple, feasible, practical, reliable, and valid alternative to laboratory-based tests and have been recommended and widely used among children (Ruiz et al. 2009b). In addition, field-based tests do not usually require sophisticated equipment, and are relatively inexpensive, time efficient and easily administered to large numbers of participants at the same time (Tomkinson et al. 2019b; Raghuveer et al. 2020). These field-based tests, which do not require maximal effort are referred to as submaximal exercise tests and they estimate CRF using equations or nomograms that have been validated against a maximal exercise test. Although submaximal tests are easier to perform, they may lead to measurement errors. The measurement and reporting of CRF depend on several factors; the test and its protocol used, whether CRF is measured or estimated, whether CRF measures are reported as absolute values or indexed to body size, and participant motivation (Tomkinson et al. 2003). However, these tests are useful for identifying children with low or unhealthy CRF levels (Raghuveer et al. 2020). Regarding the physical fitness components assessed, CRF was contemplated in all the fitness test batteries monitoring the health among children and adolescents in a recent systematic review (Marques et al. 2021). The most common and widely used field test for assessing CRF in children is the 20-meter shuttle run test (20 m SRT), also known as the maximal multistage 20-meter shuttle run test (20-MST) (Léger & Lambert 1982; Léger et al. 1988; Tomkinson et al. 2019b).

2.3.1.2 Cardiorespiratory fitness and weight status

Cross-sectional and longitudinal studies have shown strong inverse associations between CRF and weight status (Johnson et al. 2000; Koutedakis et al. 2005; Byrd-Williams et al. 2008; Lang et al. 2018; Lang et al. 2019). Further, it has been speculated that a significant proportion of the reported decline in CRF may be attributable to the increasing prevalence of obesity (Tomkinson et al. 2019a), and longitudinal studies have found lower CRF in childhood or declines in CRF over the years to be associated with a higher prevalence of obesity later in life (Dwyer et al. 2009; Mota et al. 2009). However, most of the studies have used BMI, WC, or sum of skinfolds, rather than more sophisticated measures of adiposity (Lang et al. 2018). The research on the association between CRF and abdominal adiposity in pediatric population is still emerging, but there is evidence that CRF is inversely associated with abdominal adiposity in youth (Raghuveer et al. 2020). In addition, in a recent study of overweight and obese children, better performance in CRF tests was strongly associated with lower abdominal adiposity, as assessed by magnetic resonance imaging (MRI) (Medrano et al. 2022). Further, evidence from recent studies suggests that having moderate to high levels of CRF may attenuate the deleterious metabolic consequences caused by total and abdominal adiposity in children, even without changes in weight status (Schmidt et al. 2016; Ortega et al. 2018b; Vukovic 2019; Chiesa et al. 2020).

2.3.2 Muscular fitness

MF is another component of HRF and can be divided into muscle endurance and muscle strength, which are the MF dimensions that have been most frequently used in fitness test batteries in children. Muscle endurance relates to a muscle's ability to continue to perform without fatigue, while muscle strength relates to the ability of a muscle to exert force (Ortega et al. 2008; Smith et al. 2014; Marques et al. 2021). In addition, increasing muscle mass is recognized as an independent marker of metabolic health in children (Cossio Bolaños et al. 2019).

2.3.2.1 Assessment of muscular fitness

There are several test batteries to evaluate different dimensions of MF in children (Institute of Medicine 2012; Fraser et al. 2021; Marques et al. 2021). Different measurement protocols influence the safety and purpose, as well as the reliability and validity of the assessments (Plowman & Meredith 2013). Generally, it has been shown that field tests provide satisfactory results when compared to laboratory-based tests for studying MF in children with different weight status (Thivel et al. 2016). A total of 56 different MF tests for children and adolescents were identified in a recent systematic review (Marques et al. 2021), but no single test adequately describes an individual's overall MF level (Institute of Medicine 2012; Fraser et al. 2021), which means several different tests should be used. Regarding the physical fitness components assessed, upper body strength was contemplated in all the fitness test batteries included in the systematic review of research assessing MF (Marques et al. 2021).

2.3.2.2 Muscular fitness and weight status

Associations between MF and weight status in childhood have received less scholarly attention than CRF and weight status, and most of the data available from previous studies are based on BMI or other anthropometric measures (Smith et al. 2014; Thivel et al. 2016; García-Hermoso et al. 2019). Inverse associations between MF and BMI, WC, and skinfolds were found in a systematic review and meta-analysis, that evaluated the potential health benefits associated with MF among children and adolescents (Smith et al. 2014). In another systematic review, higher MF values were related to lower WC values (de Lima et al. 2020). In a systematic review examining MF in obese children (Thivel et al. 2016), it was concluded, that further studies were needed to explore MF in the obese pediatric population because of the small number of previous studies and their conflicting results. In addition, in a systematic review and meta-analysis of longitudinal studies, a moderate but significant prospective negative association was observed in childhood and adolescence between MF and BMI and skinfolds in later life (García-Hermoso et al. 2019). It was concluded that due to the heterogeneity of the results, further studies were needed to clarify the relationship between MF in children and future weight status. In yet another meta-analysis small but significant effects of resistance training interventions in youth on different measures of body fat percentage (BF%) were found, but there were no significant overall effects on body mass, BMI, FFM, fat mass, lean mass, or WC (Collins et al. 2018). Studies of the association between MF and abdominal adiposity in pediatric populations remain still scarce, but in one recent study, better performances on an MF handgrip test were associated with lower MRI-assessed abdominal adiposity in overweight and obese children (Medrano et al. 2022).

It has been proposed that MF is heavily influenced by body weight in children aged 6 to 17, especially when assessed with weight-bearing tests (Ruiz et al. 2009a). However, a recent meta-analysis showed that MF, as measured both in absolute terms and relative to body weight, was inversely associated with adiposity later in life; the effect sizes reported using different tests (upper, middle, and lower body strength or endurance) were similar (García-Hermoso et al. 2019).

3 PURPOSE OF THE THESIS

The overall purpose of this thesis was to examine the associations of FMS, CRF, and MF with total body and abdominal adiposity and BMI-defined weight status in children. To address this purpose, the following main aims identified:

1. To give an overview of studies providing evidence for a relationship between fundamental movement skills and weight status in children aged 3 to 12 (Study I)

2. To examine the associations of fundamental movement skills with total body and abdominal adiposity in eight-year-old children (Study II)

3. To examine the associations of cardiorespiratory fitness with total body and abdominal adiposity in eight-year-old children (Study III)

4. To examine the associations of muscular fitness with total body and abdominal adiposity in eight-year-old children (Study IV)

4 METHODS

Study I was a systematic review, while Studies II, III and IV were cross-sectional studies of the same study population. The samples and methods used are described below.

4.1 Systematic review (Study I)

Systematic searches of five electronic databases (MEDLINE [PubMed], SportDiscus, ERIC, PsycInfo, and SCOPUS) were conducted in January 2015 by an experienced informatician. Key words included motor skill, movement skill, fundamental movement skills, object control skill, locomotor skill, motor competence, motor proficiency, motor ability, obesity, overweight, weight status, body mass index, BMI, body composition, waist circumference, body fat, fatness, children, child, youth, kindergarten, and preschool children. All together the systematic review (Study I) consisted of 12 different cross-sectional studies published between 2004 and 2014 of children from five continents aged 3–12. The number of study participants in the studies ranged from 38 to 4,650.

4.1.1 Eligibility of the studies

The searches identified 783 references from the five electronic databases. Titles and abstracts of potentially relevant references were checked after removal of duplicates, after which full-text copies of potentially relevant citations were obtained. Two authors independently reviewed the full-text articles and assessed the eligibility of each study for inclusion. The inclusion criteria were as follows: (a) participants were aged 3–12; (b) at least two FMS were assessed by a process- or product-oriented measurement; (c) a summary of FMS performance (reported as total FMS score, object control score, or locomotor score) was included in the analysis; (d) a quantitative analysis of the relationship between FMS and weight status was found; (e) only gross motor skills were assessed, with fine motor skill scores not included in analyses; and (f) the study was published in English in a peer-reviewed journal. Studies with special populations or underweight subjects, intervention studies, and studies that evaluated only overweight or obese children or adolescents, fine motor skills, HRF, or motor abilities were not included. If there was uncertainty about including an article, the article in question was jointly reviewed by the two authors until a final decision was made. All together 14 studies met the inclusion criteria.

4.1.2 Assessment of quality of the studies

The two authors independently assessed the quality of the 14 eligible studies. The criteria for assessing the quality of the studies were adopted from Lubans et al. (2010) based on the STROBE (von Elm et al. 2007) and CONSORT (Moher et al. 2001) statements. A quality score for each study was completed on a six-point scale by assigning a value of zero (absent or inadequately described) or one (explicitly described and present) to each of the following questions: (a) Did the study describe the participants' eligibility criteria? (b) Were the participants randomly selected? (c) Did the study report the details of FMS assessment, and did the instruments have acceptable reliability for the specific age group? (d) Did all the methods have acceptable reliability? (e) Did the study report a power calculation, and was it adequately powered to detect hypothesized relationships? (f) Did the study report the numbers of individuals who completed each of the different measures and completed at least 80% of them? Studies that scored 0–2 were classified as low quality, 3–4 as medium quality, and 5–6 as high quality. Two low-quality studies were excluded from the analyses; thus, the final sample in the systematic review contained 12 studies. The search strategy and the assessment of quality of the included studies are reported in greater detail in the original paper.

4.1.3 Categorization of variables and level of evidence

The relationship between FMS performance and weight status was determined by examining the percentage of studies that reported a statistically significant relationship. Results were coded using the method previously employed by Lubans et al. (2010), with the following criteria adopted: (a) lack of scientific evidence if less than 33% of studies indicated a significant association between variables or if none of the studies deemed to have a low risk of bias found a significant association; (b) uncertain evidence if 34%–59% of the studies indicated a significant association between variables, with at least one deemed to have a low risk of bias; (c) positive evidence if 60%–100% of the studies indicated a significant association between variables and 34%–59% of the studies deemed to have a low risk of bias found a significant association in the same direction; (d) strong evidence if 60–100% of the studies indicated a significant association between variables in the same direction and more than 59% of the studies were deemed to have a low risk of bias (score ≥ 5) found a significant association

4.2 Cross-sectional studies (Studies II, III, IV)

For the three cross-sectional studies, a random sample (N= 750) of children born in 1997 and living in Tampere, Finland, was drawn from the Population Register of the City of Tampere. An invitation letter to participate in the study was mailed to children and their parents at their street addresses by the UKK Institute – Centre for Health Promotion Research. A reminder was sent to families who did not respond to the first letter. The families willing to participate in the research booked an appointment at the UKK Institute, and in total 304 children and one of their parents participated in data collection for the study between October 2005 and July 2006, when the children were approximately eight years old. All the measurements were performed at the UKK Institute during a single visit. The participants in Studies II, III, and IV comprised 151 girls and 53 boys (mean 8.6 years; range 8.2–9.2 years).

4.2.1 Assessments of body composition and anthropometrics

Body composition and anthropometric measurements (Figure 1) were performed individually in the presence of each child's parent by trained research nurses. Total body adiposity, abdominal adiposity, and FFM were measured with DXA (GE Lunar Prodigy Advance, GE Lunar Radiation Corp., Madison, WI, USA). Abdominal adiposity, which includes intra-abdominal fat and subcutaneous fat, was assessed in a manually delineated region of interest that included the soft tissue area of the body between the lowest ribs and the superior border of the iliac crest. According to repeated measurements of 22 adults, the in vivo precision of these measurements was 1.3% for total body adiposity, 2.2% for abdominal adiposity, and 0.7% for FFM (Sievänen, unpublished data). Height and weight were measured in light clothing and without shoes. Height was measured to the nearest 0.1 cm, while weight was determined using a high-precision electronic scale (F 150S-D2, Sartorius AG, Göttingen, Germany) to the nearest 0.1 kg; these measurements were then used to calculate BMI (kg/m^2). WC was measured in triplicate by a measuring tape midway between the lowest rib and the superior border of the iliac crest. The average of the three WC measurements was used in all analyses.

4.2.2 Assessment of fundamental movement skills

The TGMD-2 (Ulrich 2000) was used to assess FMS. The TGMD-2 assesses two dimensions of gross motor performance; six locomotor skills (run, horizontal jump, slide, gallop, leap, and hop) and six object control skills (strike, basketball dribble, throw, catch, kick, and underhand roll) and all the FMS in the TGMD have between three and five performance criteria (Ulrich 2000; Goodway et al. 2019). In the present study, three locomotor skills (gallop, leap, and horizontal jump) and two object control skills (stationary dribble and overhand throw) were assessed (Figure 1). The tests were administered following standardized procedures, instructions, and demonstrations (Ulrich 2000). Before each test, the children were given a standardized visual demonstration of the correct technique for performing the skill but were not told what components were being assessed. The presence or absence of the designated criteria of form was evaluated by the assessor. A correct performance was scored as zero, and an incorrect performance was scored as one. Each of the two trials was scored independently. The sum of the scores for the two performances represents the final score for each item. The correctly performed criteria for the two trials of each of the three locomotor and the two object control skills were summed to provide raw subtest scores for locomotor skills (range 0–24/12 skill criteria) and object control skills (range 0–16/8 skill criteria). Both raw scores were used in the data analyses, as recommended for research purposes (Ulrich 2000). To transform the raw subtest scores into comparable final scores, both raw scores were standardized into a maximum score of 16. The sum of both subtests yielded the total FMS score (range 0–32). All the children were videotaped performing two trials of each task, and 25% of the children, selected at random, and all unclear cases were later double-checked on the videotape by the same assessor. The FMS test assessments were performed alone or in pairs with another child, with each child assessed individually by the experienced researcher. Before the main study, intra-observer reliability tests were conducted with 24 children in the pilot study; the videotaped performances of the two trials of the skill were assessed by the same researcher to study intra-observer agreement (intraclass correlation was 0.978 for locomotor skill and 0.995 for object control skill).

4.2.3 Assessment of cardiorespiratory fitness

The children participated in the 20 m SRT (Figure 1), which involves continuous running between two lines 20 m apart at a specific pace that increases with each minute that passes. Running speed was paced by a sound signal on a CD. Participants started at 8.0 km/h; the second stage is 9.0 km/h, with speed increasing by 0.5 km/h each minute thereafter (Olds et al. 2006). Maximal performance was reached when a child did not cross the 20 m line at the moment of the sound signal for two consecutive 20 m distances. During the test, verbal encouragement was used to motivate the children to give their best effort. The CRF test assessments were performed alone or in pairs with another child, and each child was assessed individually by the experienced researcher. The result of the test was the CRF score; that is, the number of 20 m runs completed.

4.2.4 Assessment of muscular fitness

The assessment of MF (Figure 1) was accomplished with three test items from the FitnessGram HRF test battery for children and adolescents, in accordance with the instructions outlined in the test manual (Meredith & Welk 2010). The test items chosen were a curl-up test, a trunk lift test, and a modified pull-up test. The curl-up test was used to assess abdominal muscle strength and endurance. It required each participant to perform as many curl-ups as possible following a specific cadence provided by a sound signal on CD. The score was the number of curl-ups performed. The trunk lift test was used to assess the strength of the back extensor muscles; it required each participant to lie prone, lift the upper body off the floor using the extensor muscles of the back, and hold that position while the distance from the floor was measured. The score is the distance measured in centimeters. The modified pull-up test was used to assess upper body strength and endurance; it required each participant to lie in a supine position with the body horizontally straight, grasp a bar placed just out of reach, and pull up toward the bar. The score is the number of pull-ups performed. The MF test assessments were performed alone or in pairs with another child, and each child was assessed individually by the experienced researcher.

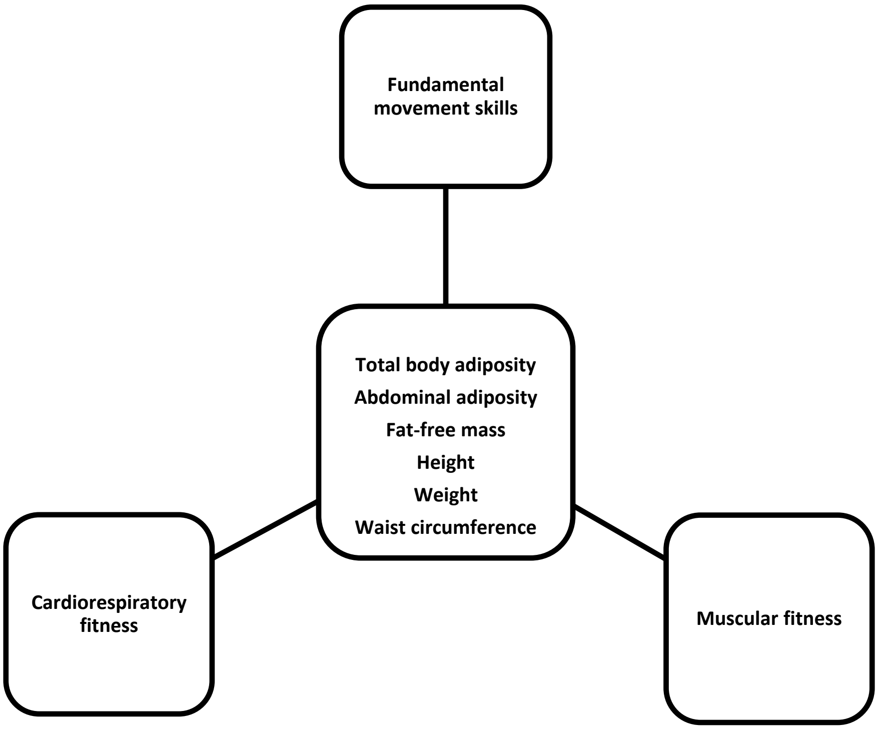

FIGURE 1 Assessments of the cross-sectional studies (Studies II, III and IV)

4.3 Statistical analyses

4.3.1 Study I

Eligibility, assessment of quality, and categorization of variables and level of evidence of the studies included in the systematic review (Study I) sre described in the section 4.1.

4.3.2 Studies II, III, and IV

Before the statistical analyses, all data were checked for normality. The BMI (kg/m^2) of each participant was calculated by dividing weight (in kg) by the square of height (in m) and participants were classified as healthy weight, overweight or obese, according to the BMI cut-offs of the International Obesity Task Force (IOTF) for age and sex (Appendix 2) (Cole et al. 2000), as recommended by the European Childhood Obesity Group (Rolland-Cachera 2011).

In Study II, the IOTF cut-off points (Cole et al. 2000), were used to classify the children as healthy weight, overweight, or obese and then assigned to one of two categories: healthy weight or overweight/obese. Based on the CRF test performance, the children were placed in three groups: low CRF (lowest third), moderate CRF (middle third) and high CRF (highest third) according to sex-specific percentiles. A one-way analysis of variance (ANOVA) was used to examine differences in participant characteristics across the CRF groups; when an ANOVA result was statistically significant ($p < 0.05$), a Tukey's post hoc comparison test was used to identify specific between-group differences. Analysis of covariance (ANCOVA) was used to determine the associations of CRF and BMI and their interactions with WC, BF%, and abdominal fat percentage (AF%) in different BMI categories (normal weight, overweight/obese). The dependent variables (WC, BF%, and AF%) were included in the models in their original continuous scales of measurement; CRF group (low, moderate, high) and BMI category (normal, overweight/obese were entered as factor variables. All models included age and sex as covariates. Models were run separately for each of WC, BF%, and AF%. The influence of CRF on WC, BF%, and AF% was determined using ANCOVA. The dependent variables (WC, BF%, and AF%) were included in the models in their original continuous scales of measurement, and the CRF group (low, moderate, or high) was entered as a factor variable. All models included age, sex, and BMI in continuous form as covariates. Models were run separately for each of WC, BF%, and AF%.

In Study III, means and standard deviations were calculated for all variables and prior to analysis, normality and equality of variances of the groups were assessed using the Kolmogorov–Smirnov test (with Lilliefors' correction) and the Levene test, respectively. Based on the test performance, the children were assigned to three groups: low FMS (lowest third), moderate FMS (middle third) and high FMS (highest third). According to the IOTF cut-off points (Cole et al., 2000), children were classified as healthy weight, overweight or obese and then assigned to two categories, healthy weight or overweight/obese, for statistical analysis. A one-way ANOVA was used to examine the differences in participant characteristics across the FMS groups; when an ANOVA result was statistically significant ($p < 0.05$), a Tukey's post hoc comparison test was used to identify specific between-group differences. When the variables were normally distributed, *t*-test and *F*-test were used. When the variables were shown to be non-normal, the Mann–Whitney U-test was used to test the difference between two groups, the Kruskal–Wallis test for differences between several groups, and Spearman's rank-order correlation when assessing the associations between the variables. Exact *p*-values are reported for non-parametric statistics. Cohen's *d* was used as an indicator of the effect size (the values of Cohen's *f* were transformed to values of Cohen's *d*). Tukey's test was used in the post hoc analysis.

In Study IV, means and standard deviations were calculated for all variables. The standardized total MF score was computed from the three test item scores. The three MF test item scores were standardized separately for both sexes, after which the different MF-variables were combined into one variable, and finally divided into the thirds of the obtained variable: low MF (the lowest third), moderate MF (the middle third) or high MF (the highest third). The participants were classified as healthy weight, overweight or obese, according to the IOTF BMI cut-offs (Cole et al. 2000) and then assigned to one of two categories: healthy weight or overweight/obese. Pearson's correlation coefficient was used to assess the correlations between variables, while ANOVA was used to examine differences in participant characteristics across the MF groups. When an ANOVA result was statistically significant ($p < 0.05$), a Tukey's or Tamhane's post hoc comparison test was used to identify specific between-group differences. The influence of MF on BF% and AF% was determined using an ANCOVA. The dependent variables (BF% and AF%) were included in the models in their original continuous scales of measurement, with MF group (low, moderate, or high) entered as a factor variable. All models included BMI, sex, and CRF as covariates, and all models were run separately for BF% and AF%.

All analyses were carried out using IBM Statistical Package for Social Sciences (SPSS) Statistics for Windows: version 20.0 for Study II (IBM Corp, Armonk, NY, USA), version 15.0 for Study III (SPSS Inc., Chicago, IL, USA), and version 26 for Study IV (IBM Corp, Armonk, NY, USA). Statistical significance probability (*p*-value) was set at an alpha level of 0.05 for all analyses. Table 2 summarizes the main statistical analyses implemented in each of Studies II, III, and IV.

4.4 Ethics

In participant recruitment, assessments, data collection, and analysis for Studies II, III, and IV, the researcher and research nurses adhered strictly to the principles of good scientific behavior and unconditional confidentiality. Each participant's identity was replaced with an ID code to secure anonymity, and no individuals were identifiable when the results were published. The data were kept on the UKK Institute's computer and the researcher's personal computer, which were accessible only with the user's personal code. During all research phases, the data were kept confidential and used only for the purpose of this study.
The children and their parents were informed about the purpose and nature of the study and all the measurements beforehand in an invitation letter and at the research site. The children and their parents received information related to DXA measurement and associated radiation dose levels. The effective dose received

from natural background radiation in one day is about 10 μSv. For a typical DXA examination, the patient dose is comparable to or less than this daily background dose (www.iaea.org). The radiation risks were clearly explained prior to the scan, and good radiological practices were followed. All the children were accompanied by one of their parents, and both child and parent gave written informed consent upon arrival at the research site. The study was approved by the Ethics Committee of Pirkanmaa Hospital District (reference number: R05105) in Tampere, Finland, before recruitment of participants began.

TABLE 2 Overview of the Studies I, II, III and IV of the thesis; title of the study article, main aim, sample, methods, and main analyses

	Title of the study article	Main aim	Sample	Methods	Main analyses
Study I	Fundamental movement skills and weight status in children: A systematic review.	To give an overview of studies providing evidence for a relationship between fundamental movement skills and weight status in 3–12 years old children	A total of 783 references were identified from five electronic databases. Initial screening of titles and abstracts produced 104 potentially relevant references after removal of duplicates. These references were further screened for their full text and 14 studies met the inclusion criteria. After the study quality assessment, the final sample in the review included 12 studies.	A systematic search of five electronic databases (MEDLINE (PubMed), SportDiscus, ERIC, PsycInfo and SCOPUS) was conducted in January 2015. Studies examining associations between FMS and weight status in children aged 3–12 years were included.	The relationship between FMS performance and weight status was determined by examining the percentage of studies that reported a statistically significant relationship. Two authors independently assessed the eligibility of the studies for inclusion. Two authors independently assessed the quality of the eligible studies, using the criteria adopted from Lubans et al. based on the STROBE and CONSORT statements.
Study II	Fundamental movement skill proficiency and body composition measured by dual energy X-ray absorptiometry in eight-year-old children.	To examine the associations of fundamental movement skills with total body and abdominal adiposity in eight-year-old children	Complete data for FMS, body composition and anthropometric measurements, for 304 eight-year-old children (151 girls and 153 boys)	TGMD-2 was used to assess FMS. WC, height and weight were measured and IOTF BMI cut offs for healthy weight, overweight and obesity were used. BF%, AF% and FFM were assessed with DXA	A one-way ANOVA was used to examine the differences in participant characteristics across the FMS and BMI groups and Spearman's correlations between object control, locomotor and total FMS and different body composition variables in boys and girls.

	Title of the study article	Main aim	Sample	Methods	Main analyses
Study III	Eight-year-old children with high cardiorespiratory fitness have lower overall and abdominal fatness.	To examine the associations of cardiorespiratory fitness with total body and abdominal adiposity in eight-year-old children	Complete data for CRF, self-reported PA and sedentary time, body composition and anthropometric measurements, for 304 eight years old children (151 girls and 153 boys)	CRF was assessed with 20-mSRT, questionnaire reported PA and sedentary time minutes were calculated, WC, height and weight were measured and IOTF BMI cut offs for healthy weight, overweight and obesity were used. BF%, AF% and FFM were assessed with DXA	ANCOVA was used to determine the differences across CRF groups and BMI categories in WC, BF% and AF%, controlling for age and sex. The influence of CRF on WC, BF% and AF% was determined using ANCOVA. All models included age, sex and BMI as covariates.
Study IV	Associations of muscular fitness and body composition in eight-year-old children.	To examine the associations of muscular fitness with total body and abdominal adiposity in eight-year-old children	Complete data for MF, body composition and anthropometric measurements, for 304 eight years old children (151 girls and 153 boys)	MF was assessed with three tests of the FitnessGram test battery. WC, height and weight were measured and IOTF BMI cut-offs for healthy weight, overweight and obesity were used. BF%, AF% and FFM were assessed with DXA	A one-way ANOVA was used to examine differences in participant characteristics across the MF groups and BMI groups. The influence of MF on BF% and AF% was determined using ANCOVA, including CRF, BMI and sex as covariates.

5 OVERVIEW OF RESULTS

This chapter presents an overview of the findings of four studies conducted for this dissertation; they aimed to extend knowledge of the associations between FMS and weight status and total body and abdominal adiposity in children (Studies I and II), and the associations of CRF and MF with total body and abdominal adiposity in children (Studies III and IV).

5.1 Fundamental movement skills and weight status

The systematic review (Study I) aimed to provide an overview of studies examining the relationships between FMS and weight status in children aged 3–12 and featured 12 cross-sectional studies published between 2004 and 2014. When associations between FMS total score and weight status were examined, seven of the 12 included studies found statistically significant inverse associations between total FMS scores and BMI. Three were classified as high quality, assessed by the criteria reported in detail in section 4.1.2 (Assessment of quality of the studies). Five studies did not demonstrate statistically significant associations between FMS score and BMI, one of which was classified as high quality. Three studies used WC; significant inverse associations were found in two of these studies, both of which were classified as high quality. One study, which used skinfolds, found no statistically significant association. One study used DXA and found a significant association between FMS and total body and abdominal adiposity.

As to locomotor skills and weight status, inverse associations between locomotor skills and weight status were found in six studies, three of which were classified as high quality. Two studies found no significant association between locomotor skills and weight status. When association between object control skills and weight status was examined, inverse associations between object control skills and weight status were found in three studies, one of which was classified as high quality. Five studies reported no significant association between object control skills and weight status, three of which were classified as high quality. As to stability skills and weight status, inverse associations between stability skills and weight status were found in two studies; in one study, the association was not significant. None of these were classified as high-quality studies.

5.2 Participants in the cross-sectional studies

The participants (N=304; 151 girls and 153 boys) in the three cross-sectional studies (Studies II, II, and IV) were approximately eight years old during the measurements, with a mean of 8.6 years and a range of 8.2–9.2 years. According to the IOTF BMI cut-offs (Cole et al. 2000; Rolland-Cachera 2011), 80.9% were healthy weight (girls 81.5%; boys 80.4%), 17.1% were overweight (girls 17.9%; boys 16.3%), and 2.0% were obese (girls 0.7%; boys 3.3%).

There were no statistically significant differences between girls and boys in age, BMI, WC, weight, or height. The DXA measured BF% and AF%, and FFM differed between the sexes; girls had significantly higher AF% and BF% than boys, and boys had significantly more FFM than girls (Table 3).

When the raw FMS subtest scores were divided by sex, boys were found to be more proficient at object control skills, while girls were more proficient at locomotor skills. For total FMS, however, boys scored significantly higher. There were between-sex differences in CRF, with boys scoring significantly higher than girls. In the MF test results, girls were more proficient than boys in the curl-up and trunk lift tests. No significant differences between sexes were found in the modified pull-up test (Table 3).

TABLE 3 Descriptives of the participants. Means (SD)

	All (N = 304)	Girls (n = 151)	Boys (n = 153)	*P*
Weight (kg)	30.9 (5.6)	30.7 (5.5)	31.2 (5.6)	.482
Height (cm)	134.2 (5.8)	133.8 (5.6)	134.7 (6.0)	.174
BMI (kg/m^2)	17.1 (2.1)	17.1 (2.1)	17.1 (2.2)	.971
Waist circumference (cm)	59.7 (6.2)	59.3 (6.1)	60.1 (6.2)	.286
Total body fat (%)	21.6 (7.7)	24.0 (6.9)	19.2 (7.7)	< .001
Abdominal region fat (%)	23.3 (11.2)	26.5 (10.5)	20.2 (10.9)	< .001
Fat-free mass (kg)	22.7 (2.8)	21.8 (2.5)	23.6 (2.8)	< .001
Fundamental movement skills tests				
• Object control skills (range 0–16)	11.4 (3.8)	9.4 (3.3)	13.3 (3.3)	< .001
• Locomotor skills (range 0–24)	15.8 (3.3)	16.4 (3.3)	15.2 (3.2)	.002
• Total FMS (range 0–32)	21.9 (4.8)	20.3 (4.5)	23.5 (4.5)	< .001
Muscular fitness tests				
• Curl up (reps)	11.0 (11.8)	12.9 (12.4)	9.2 (10.9)	.006
• Trunk lift (cm)	14.1 (3.8)	15.5 (3.8)	12.8 (3.4)	< .001
• Modified pull-up (reps)	5.5 (4.4)	5.2 (4.0)	5.8 (4.8)	.250
Cardiorespiratory fitness test				
• 20-m shuttle run (laps)	22.5 (8.5)	20.6 (7.2)	24.2 (9.5)	< .001

5.3 Fundamental movement skills and adiposity

When FMS were examined by BMI groups (Table 4), FMS proficiency was significantly lower in overweight/obese children than in healthy weight children in all three FMS categories: object control skills, locomotor skills, and total FMS.

TABLE 4 Characteristics of the children divided into BMI groups. Means (SD)

Variables	Healthy weight (*n* = 246) Mean (SD)	Overweight/obese (*n* = 58) Mean (SD)	*P*	Cohen's *d*
Age	8.6 (0.2)	8.6 (0.2)	0.26	−0.17
BMI	16.3 (1.2)	20.4 (2.0)	<0.001	−2.90
AF (%)	19.9 (8.8)	37.7 (8.7)	<0.001	−2.04
BF (%)	19.3 (6.2)	31.4 (5.4)	<0.001	−2.02
WC (cm)	57.6 (3.9)	68.3 (6.4)	<0.001	−2.39
OC	11.7 (3.7)	9.9 (3.9)	0.001	0.49
LM	16.3 (3.1)	13.4 (3.2)	<0.001	0.95
Total FMS	22.6 (4.5)	18.8 (4.8)	<0.001	0.84

Note: AF: abdominal fat, BF: total body fat, BMI: body mass index, LM: locomotor skills raw score (range 0–24), OC: object-control skills raw score (range 0–16), Total FMS: total fundamental movement skills score (range 0–32), WC: waist circumference.

When girls and boys were divided into low, moderate, and high FMS groups, BF% and AF% among boys were significantly higher in the low FMS group than in the moderate and the high FMS groups (Table 5). In addition, the moderate FMS group differed significantly from the high FMS group. Among girls, BF% and AF% were significantly higher in the low FMS group than in the high FMS group. In both sexes, BMI, WC, and weight were also higher in the low FMS group than in the high FMS group.

TABLE 5 Characteristics of boys and girls divided into FMS groups. Means (SD)

	Variables	Low ($n = 28$) Mean (SD)	Moderate ($n = 53$) Mean (SD)	High ($n = 72$) Mean (SD)	P	η^2	Cohen's d	Tukey
Boys	Age	8.7 (0.2)	8.6 (0.2)	8.6 (0.2)	0.187	0.022	0.37	ns
	BMI	18.2 (2.4)	17.2 (2.4)	16.6 (1.7)	0.003	0.073	0.69	13
	Height (cm)	135.1 (5.8)	135.9 (6.3)	133.6 (5.7)	0.112	0.029	0.42	ns
	Weight (kg)	33.3 (5.9)	31.9 (6.1)	29.7 (4.7)	0.007	0.065	0.65	13
	WC (cm)	63.2 (7.1)	60.4 (6.5)	58.6 (5.2)	0.003	0.074	0.69	13
	BF (%)	25.1 (8.4)	19.8 (7.7)	16.5 (5.9)	<0.001	0.17	1.11	12 13 23
	AF (%)	28.1 (11.9)	20.6 (11.5)	16.8 (8.3)	<0.001	0.141	0.99	12 13 23
	FFM (g)	23340.5 (2240.8)	23927.7 (3025.3)	2341.1 (2752.7)	0.52	0.009	0.23	ns
	OC (range 0–16)	8 (3.4)	13.3 (1.8)	15.4 (0.8)	<0.001			12 13 23
	LM (range 0–24)	11.7 (3.1)	14.1 (2.2)	17.3 (2.1)	<0.001			12 13 23
	Total FMS (range 0–32)	15.8 (3.6)	22.7 (1.2)	27.0 (1.6)	<0.001			12 13 23
	Variables	Low ($n = 73$) Mean (SD)	Moderate ($n = 49$) Mean (SD)	High (n=29) Mean (SD)	P	η^2	Cohen's d	Tukey
Girls	Age	8.6 (0.2)	8.6 (0.2)	8.6 (0.2)	0.513	0.009	0.23	ns
	BMI	17.6 (2.6)	16.8 (1.6)	16.3 (1.1)	0.014	0.056	0.60	13
	Height (cm)	134.1 (6.4)	134.3 (4.5)	132.0 (5.3)	0.186	0.023	0.38	ns
	Weight (kg)	31.8 (6.7)	30.4 (4.1)	28.5 (3.5)	0.024	0.049	0.56	13
	WC (cm)	60.6 (7.3)	58.9 (4.6)	56.6 (3.5)	0.01	0.061	0.62	13
	BF (%)	25.4 (7.7)	23.5 (6.0)	21.3 (5.2)	0.018	0.053	0.58	13
	AF (%)	28.9 (11.4)	25.9 (9.8)	21.8 (7.6)	0.007	0.064	0.64	13
	FFM (g)	22123.9 (2940.1)	21880.0 (2044.0)	21081.3 (2090.4)	0.173	0.023	0.38	ns
	OC (range 0–16)	7.0 (2.6)	10.7 (1.6)	13.4 (1.7)	<0.001			12 13 23
	LM (range 0–24)	14.5 (2.7)	17.1 (2.2)	19.9 (2.7)	<0.001			12 13 23
	Total FMS (range 0–32)	16.6 (2.7)	22.1 (1.1)	26.7 (2.1)	<0.001			12 13 23

Note: AF: abdominal fat, BF: total body fat, BMI: body mass index, FFM: fat-free mass, LM: locomotor skills raw score, OC: object-control skills raw score, 1: Low, 2: Moderate, 3: High, Total FMS: total fundamental skills score, WC: waist circumference.

The correlations of FMS with BF%, AF%, WC, and BMI were examined. All four variables were significantly inversely correlated with FMS proficiency (object control, locomotor, and total FMS) in both sexes. All four variables also showed stronger correlations in boys than in girls. BF% was the strongest predictor of each of the FMS proficiency variables in boys. Among girls, object control skills showed the strongest correlation with AF% and locomotor skills the strongest correlation with WC.

5.4 Cardiorespiratory fitness and adiposity

BMI, WC, BF%, and AF% were all significantly higher in the low CRF group than in the moderate and high CRF groups in both sexes. When the associations were examined separately by BMI category, BF% and AF% were significantly higher in the low CRF group than in the moderate and high CRF groups; this was true for both healthy weight and overweight/obese children. WC was higher in the low CRF group than in the high CRF group among healthy weight children.

When differences in BF% and AF% were examined across CRF groups and BMI categories, controlling for age and sex (Figure 2), CRF was significantly inversely related to both BF% and AF%. In overweight/obese children, the high

CRF group's BF% and AF% were on average 5.5 percentage points and 7.2 percentage points lower, respectively, when compared with the low CRF group. Healthy weight children showed similar between-group differences (5.0 percentage points and 7.1 percentage points, respectively).

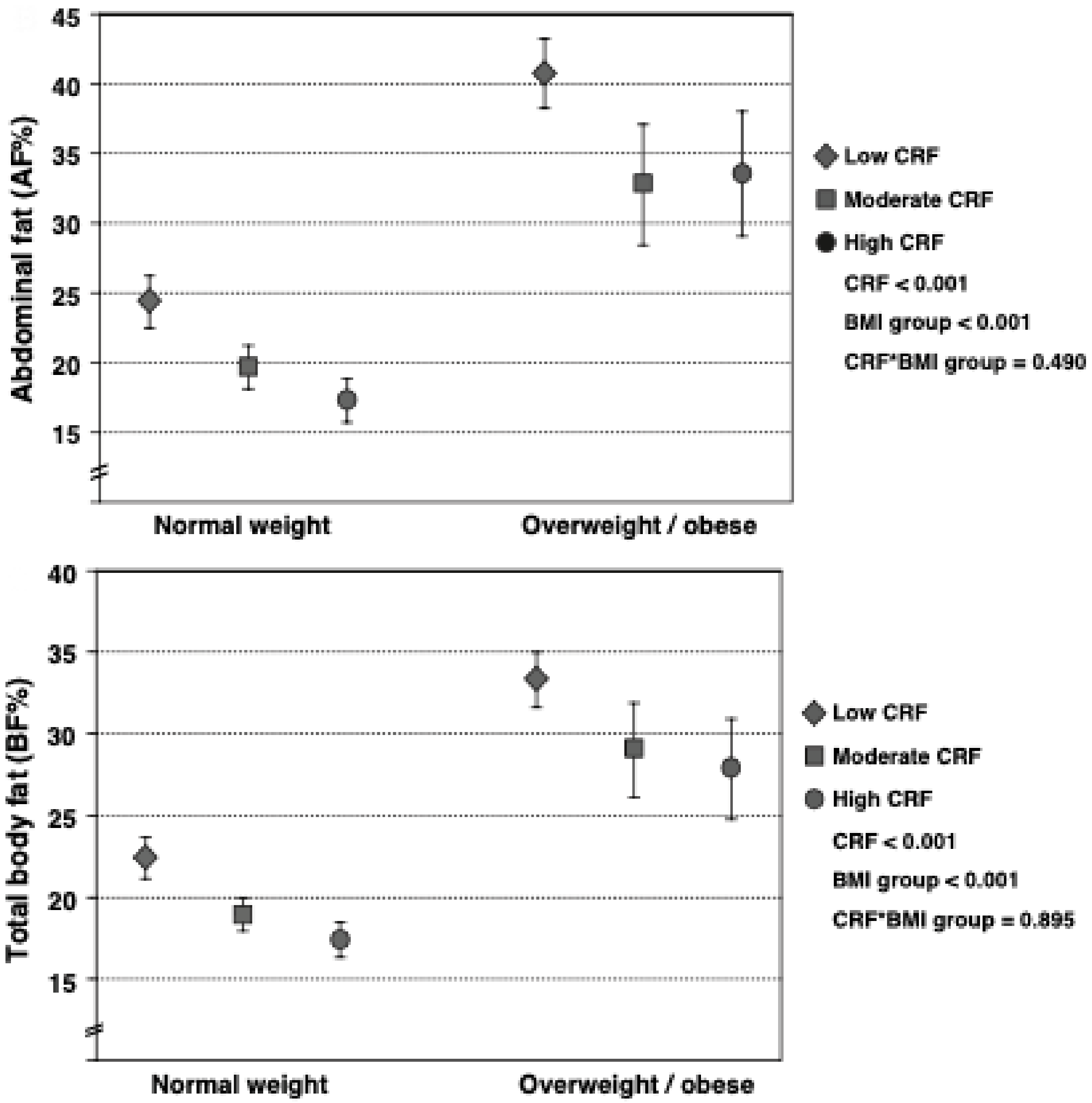

FIGURE 2 Difference across CRF groups and BMI categories in abdominal fat percentage (AF%) and total body fat percentage (BF%), adjusted for sex and age

When examining the influence of CRF after controlling for age, sex and BMI as a continuous variable, the differences between CRF groups were significant for BF% and AF% (Figure 3).

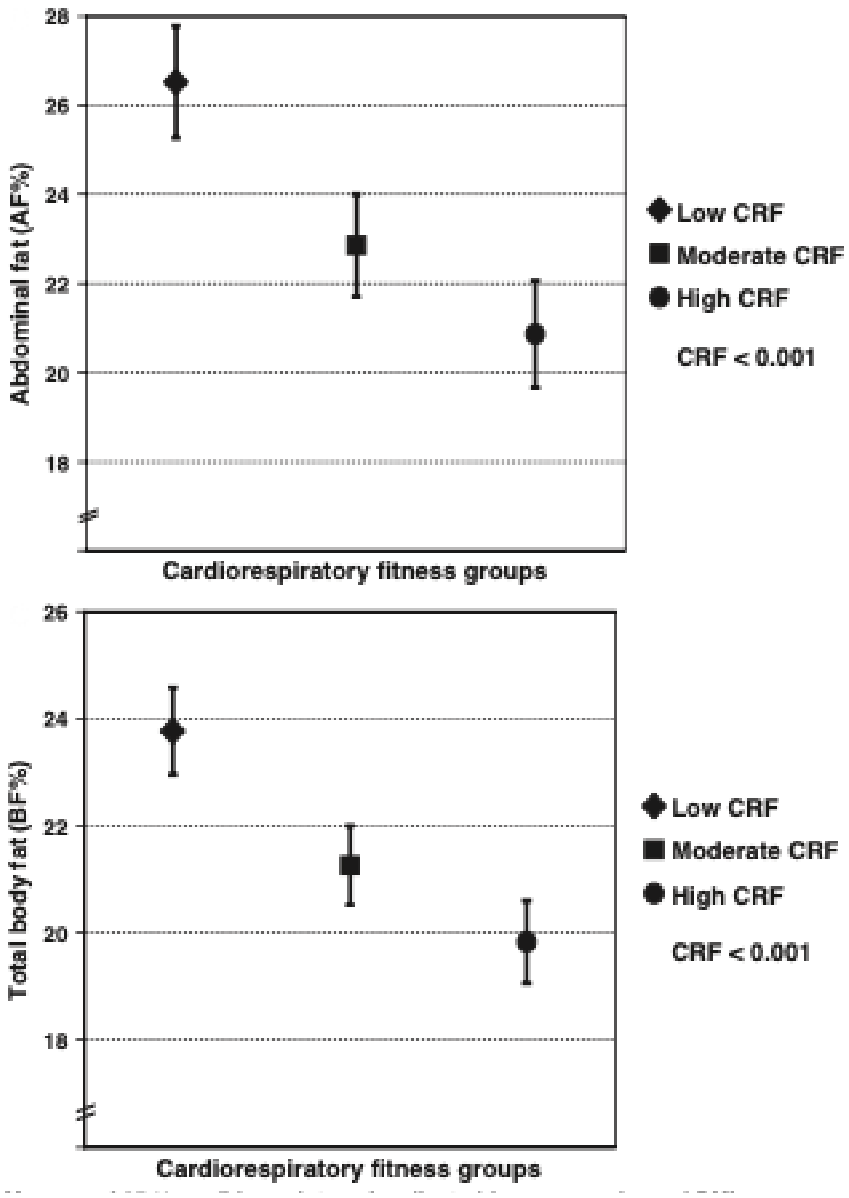

FIGURE 3 Mean age, sex and BMI adjusted values for low, moderate and high CRF groups for abdominal fat percentage (AF%) and total body fat percentage (BF%)

5.5 Muscular fitness and adiposity

When the MF test items were examined separately, the strongest correlations were found between BF% and modified pull-up and AF% and modified pull-up in both sexes. Furthermore, BF% and AF% were significantly correlated with total MF score in both sexes. A significant correlation was also found between FFM and modified pull-up performance among boys.

When the children were divided into different MF groups (low, moderate, and high MF) based on their total MF scores (Table 6), significant differences in weight, BMI, and WC were found between MF groups in both sexes. Furthermore, BF% and AF% were significantly higher for both sexes in the low MF group than in the moderate and high MF groups.

TABLE 6 Anthropometrics and body composition of the girls and boys by the MF groups (low, moderate and high MF). Means (SD)

	Girls			Boys		
	Low MF[a] (n = 50)	Mod MF[b] (n = 50)	High MF[c] (n = 51)	Low MF[a] (n = 50)	Mod MF[b] (n = 52)	High MF[c] (n = 51)
Weight (kg)	32.7 (7.2) [c]	30.0 (4.5)	30.0 (4.0) [a]	33.1 (6.5) [b]	30.1 (4.2) [a]	30.4 (5.5)
Height (cm)	134.9 (6.1)	133.0 (5.6)	133.4 (5.1)	136.3 (6.5)	134.2 (5.8)	133.5 (5.5)
BMI (kg/m^2)	17.8 (2.8)[c]	16.9 (1.7)	16.5 (1.5)[a]	17.8 (2.6)[b]	16.6 (1.5)[a]	16.9 (2.2)
WC (cm)	62.0 (7.8)[b,c]	58.0 (4.5)[a]	58.0 (4.6)[a]	62.1 (7.2)[b]	58.9 (4.8)[a]	59.3 (6.1)
BF (%)	27.8 (7.5)[b,c]	23.0 (5.8)[a]	21.3 (6.9)[a]	22.9 (8.8)[b,c]	17.2 (5.6)[a]	17.5 (7.1)[a]
AF (%)	31.6 (11.1)[b,c]	25.5 (9.4)[a]	22.6 (9.0)[a]	24.8 (12.8)[b,c]	17.7 (7.6)[a]	18.2 (10.7)[a]
FFM (kg)	21.9 (3.1)	21.7 (2.2)	21.9 (2.5)	23.8 (2.9)	23.5 (2.7)	23.5 (2.8)

AF = abdominal region fat, BF = total body fat, FFM = fat-free mass, WC = waist circumference.

Superscripts refer to the MF category from which the relevant variable is significantly different (*p*<.05) according to Tukey / Tamhane post hoc -test.

The participants' adiposity was examined in the BMI categories and compared between the low, moderate, and high MF groups (Table 7). Among healthy weight children, BF% was significantly higher in the low MF group than in the moderate and high MF groups, and AF% was significantly higher in the low MF group than in the high MF group. Among the overweight/obese children, BF% was significantly higher in the low MF group than in the moderate and high MF groups, and the AF% was significantly higher in the low MF group than in the moderate MF group.

TABLE 7 Anthropometrics and body composition within the BMI categories (healthy weight and overweight/obese) by the MF groups. Means (SD).

	Healthy weight			Overweight/obese		
	Low MF[a]	Mod MF[b]	High MF[c]	Low MF[a]	Mod MF[b]	High MF[c]
	(n = 69)	(n = 86)	(n = 91)	(n = 31)	(n = 16)	(n = 11)
Weight (kg)	29.8 (4.4)	29.0 (3.7)	28.9 (3.4)	39.7 (6.2)[b]	35.6 (3.1)[a]	38.8 (6.0)
Height (cm)	134.5 (6.3)	133.3 (5.8)	133.1 (5.2)	138.1 (5.7)	135.4 (4.9)	137.0 (4.9)
BMI (kg/m^2)	16.4 (1.4)	16.3 (1.2)	16.3 (1.1)	20.9 (2.3)[b]	19.4 (0.8)[a]	20.5 (2.2)
WC (cm)	58.4 (4.2)	57.1 (3.6)	57.6 (4.0)	70.0 (6.9)	65.6 (3.1)	67.6 (7.6)
BF (%)	21.4 (6.8)[b,c]	18.8 (5.8)[a]	18.1 (5.7)[a]	34.1 (4.1)[b,c]	27.0 (4.9)[a]	30.2 (4.7)[a]
AF (%)	22.3 (9.4)[c]	19.6 (8.3)	18.5 (8.3)[a]	41.3 (7.0)[b]	31.9 (7.9)[a]	36.2 (9.8)
FFM (kg)	22.0 (2.9)	22.2 (2.5)	22.3 (2.3)	24.8 (2.9)	24.7 (2.3)	25.7 (3.2)

AF; abdominal region fat, BF; total body fat, FFM; fat free mass, WC; waist circumference. Superscripts refer to the MF category from which the relevant variable is significantly different (p<.05) according to Tukey or Tamhane post hoc -test.

When the associations between MF and BF% and AF% were examined, adjusting for CRF, BMI, and sex (Figure 4), the differences between MF groups were significant for BF% but not for AF%. Specifically, the significant differences in BF% were found between the high and low MF groups and between the moderate and low MF groups.

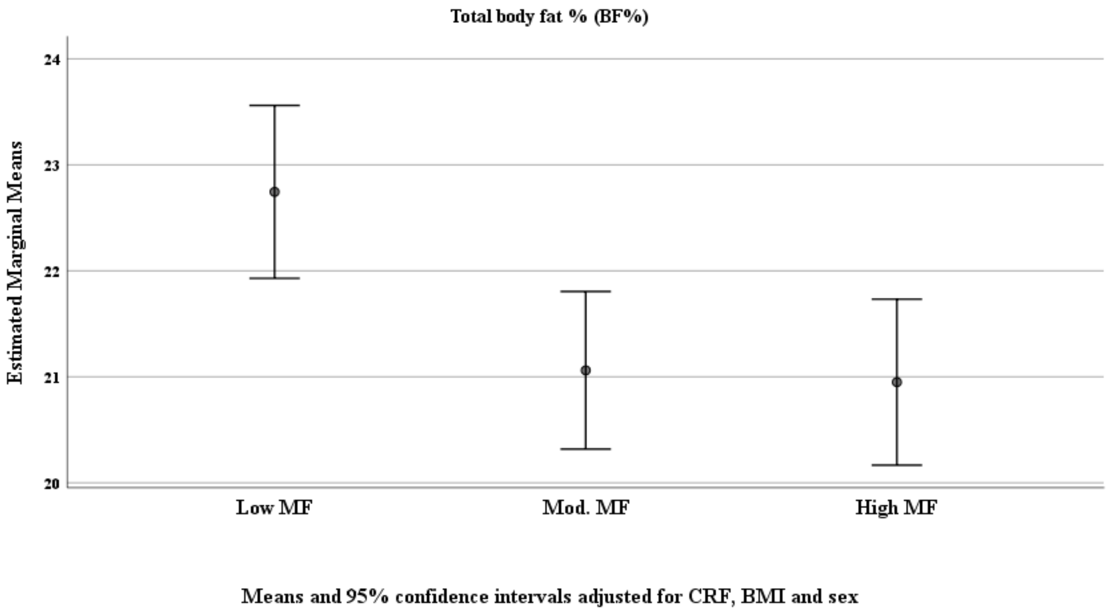

FIGURE 4 Mean CRF, BMI, and sex adjusted values for low, moderate and high MF groups and total body fat percentage (BF%)

6 DISCUSSION

The overall purpose of this dissertation was to examine the associations of FMS, CRF, and MF with BMI-defined weight status and DXA-assessed total body and abdominal adiposity in children.

6.1 Main findings

The systematic review presented in Study I gave an overview of studies providing evidence for a relationship between FMS performance and weight status in children aged 3–12. Based on the findings of the 12 studies examined, there was an inverse but weak association between FMS and weight status. The assessment methods describing and defining FMS varied, and weight status was mainly established using BMI. As adiposity and specifically abdominal adiposity are associated with less favorable cardiovascular risk factor status in children, it is important to assess weight status using more accurate methods than only BMI. More sophisticated measurements would obtain more precise evidence as to whether developing FMS competency is associated with important beneficial health consequences. In addition, measurement of FMS needs more standardized and global methods, and it may be assessed with qualitative tests that focus on the technique of the movement.

Study II (population based cross-sectional study) examined the associations of FMS with total body adiposity and abdominal adiposity, as measured with DXA in eight-year-old children. FMS proficiency (object control, locomotor, and total FMS) was inversely associated with total body adiposity and abdominal adiposity. Increased total body and abdominal adiposity were correlated with poorer FMS results. The inverse association between FMS and accurately measured adiposity is an important finding, as adiposity and specifically abdominal adiposity are associated with less favorable cardiovascular risk factor status in children.

Study III (population based cross-sectional study) explored the associations of CRF with accurately measured total body adiposity and abdominal adiposity in eight-year-old children. The findings indicated that higher CRF was significantly associated with lower total body adiposity and abdominal adiposity, independent of age, sex, and BMI, and that children with higher CRF had lower total body and abdominal adiposity compared to children with lower CRF within the same BMI category.

The purpose of Study IV (population based cross-sectional study), was to find whether MF is associated with total body and abdominal adiposity, as measured by DXA, in eight-year-old children. The results revealed significant inverse associations between MF and DXA-measured total and abdominal adiposity. Within the same BMI category, total and abdominal adiposity were lower in children with moderate or high MF than in children with low MF. After adjusting for CRF, BMI, and sex, it was found that children with higher MF had lower total adiposity than children with lower MF, but no statistically significant differences were found in abdominal adiposity between MF groups.

6.2 Participants in the cross-sectional studies (Studies II, III, and IV)

Of the participating children, 81% were healthy weight, 17% overweight, and 2% obese according to the IOTF BMI cut-offs (Cole et al. 2000; Rolland-Cachera 2011). In the light of these data, considering the distribution of healthy-weight, overweight, and obese children, as defined by the IOTF reference, the population-based sample of participating children was representative of their age group in Tampere (Vuorela et al. 2011). The data on Finnish children and adolescents aged 7–12 (based on Finnish ISO-BMI), indicate that 29% of boys and 18% of girls were overweight or obese in 2018 (National Institute for Health Welfare 2019).

Body composition as assessed by DXA differed significantly between sexes; girls had a significantly higher BF% and AF% than boys, and boys had significantly higher FFM than girls. By contrast, there were no significant differences between girls and boys in WC, weight, height, or BMI. In addition, girls' and boys' mean BMI was similar among participating children. Differences between sexes in height, weight, and body composition are generally assumed to be minimal, and growth slow and steady in the middle childhood years before pre-adolescence (Goodway et al. 2019). This was also the case among participating children, as gauged by anthropometric measures like weight, height, WC, and BMI. However, body composition accurately measured by DXA revealed significant differences between girls and boys. This is quite interesting and suggests that it may not be wise to rely solely on BMI and WC when estimating the obesity-related health status of girls and boys at the same age, as significant differences in body composition between the sexes may exist even among eight-year-old children.

6.3 Fundamental movement skills are associated with BMI-defined weight status, total body, and abdominal adiposity in children

6.3.1 Systematic review (Study I)

An overall inverse association between FMS and weight status was found in Study I; however, that relationship was weak. Of the 12 studies included in the systematic review, 58% found a significant inverse association between FMS and BMI, while 42% of the studies found no association. Furthermore, in the included studies, where WC was used, an inverse association was found in two of the three studies; the one study that used skinfolds found no significant association. Only one study used DXA; a statistically significant inverse association was found between FMS and accurately measured total body fatness and abdominal fatness.

Of the included studies, eight used process-oriented tests and four used product-oriented tests for assessing FMS. Half of the process-oriented studies and three of the product-oriented studies found significant inverse associations between FMS and BMI. Product-oriented (quantitative) assessment techniques evaluate the outcome of the movement skills and are based on time, distance, or number of successful attempts resulting from the performance of the skill, whereas process-oriented (qualitative) assessment techniques evaluate the form of movement skills (Goodway et al. 2019). Process-oriented assessments may be more suitable when assessing overweight and obese children because they more accurately identify specific characteristics of the movement, reflecting the developmental skill level instead of the maturational levels and physical growth of children.

In studies where FMS was divided into locomotor, object control, and stability skills, inverse associations were mostly found between weight status and locomotor skills rather than between weight status and object control or stability skills. The systematic review (Study I) indicates that the relationship between FMS and weight status in children is weak or somewhat unclear, which is contrary to the conclusions of two previous reviews (Lubans et al. 2010; Cattuzzo et al. 2016) but partly consistent with the results of the review and meta-analyses in Barnett et al. 2016, where it was reported that higher BMI was not correlated with object control skills, and an indeterminate association was found for locomotor skills. The explanation for these different conclusions may be that descriptions and definitions of FMS varied and different assessment methods were used in studies included in the reviews. Due to the different test batteries the components of physical fitness (e.g., flexibility, CRF, and MF) and motor fitness (e.g., speed, power, coordination, agility, balance) were also measured. It has indicated that different test batteries for assessing movement measure discrete aspects (Rudd et al. 2015). Movement skills are sometimes confused with physical fitness or motor fitness but are different (Goodway et al. 2019). The purpose of Study I was to restrict to FMS, which are generally divided into locomotor skills, object control or manipulative skills, and stability skills, which are the foundation movements for more complex and specialized skills (Goodway et al. 2019).)

As total body adiposity and specifically abdominal adiposity are associated with less favorable cardiometabolic risk factor status in children and adolescents, it is important to use more accurate methods than solely BMI to obtain more precise evidence regarding the relationship between FMS and health in children (Samouda et al. 2015; Jin et al. 2020).

6.3.2 Cross-sectional study (Study II)

The primary finding of Study II was that better FMS were significantly and strongly associated with lower total body and abdominal adiposity in eight-year-old children. The inverse associations between FMS and accurately assessed adiposity constitute an important finding, as both total body and abdominal adiposity are associated with less favorable cardiometabolic risk status in children (Kelishadi et al. 2015; Di Cesare et al. 2019; Jin et al. 2020). DXA-measured abdominal adiposity in children has been shown to be even more closely associated with health risks than total body adiposity (Jin et al. 2020). The results of Study II are notable, as research in this area in which adiposity is measured using more sophisticated techniques is scarce. In previous studies, BMI has generally been used (Lubans et al. 2010; Barnett et al. 2016; Cattuzzo et al. 2016).

BF%, AF%, WC, and BMI were all significantly inversely correlated with different categories of FMS: object control, locomotor, and total FMS in both sexes. BF% was the strongest predictor of each of the FMS categories in boys, while in girls AF% showed the strongest correlation with object control skills and WC the strongest correlation with locomotor skills. These results are contrary to the findings of a previous systematic review and meta-analysis that concluded that higher BMI was not correlated with object control skills and found an indeterminate association for locomotor skills (Barnett et al. 2016).

FMS in Study II were significantly lower among overweight and obese children than among healthy weight children in all FMS categories—object control skills, locomotor skills, and total FMS—although the difference was more notable in locomotor skills and total FMS than in object control skills. Compared to these results, previous studies have suggested that differences in FMS between healthy weight, overweight, and obese children are due mostly to differences in locomotor skills rather than object control skills (Okely et al. 2004; Southall et al. 2004).

When FMS between sexes were compared, the findings were that girls had better locomotor skills than boys and that boys had better object control skills than girls. The large effect size found for object control skills is noteworthy: boys were markedly better than girls. These findings are consistent with previous studies (van Beurden et al. 2002; Barnett et al. 2008; Barnett et al. 2010; Hardy et al. 2010). Because biology does not fully explain the differences between girls and boys in the FMS proficiency of eight-year-old children, those differences are more likely to be socially and environmentally induced (Hardy et al. 2010; Goodway et al. 2019); therefore, girls should be encouraged to practice object control skills like kicking, throwing, and catching. This is important in the context of healthier weight status, as longitudinal studies have shown that children with better object control skills are more likely to become active and fit adolescents (Barnett et al. 2008; Barnett et al. 2009).

Taken together, FMS were inversely, significantly, and strongly associated with accurately assessed total body and abdominal adiposity in eight-year-old children. According to BMI, healthy weight children had better FMS, in both object control skills and locomotor skills, than overweight and obese children. These results suggest that overweight and obese children should be supported to practice the entire range of FMS.

6.4 Cardiorespiratory fitness is associated with total body and abdominal adiposity in eight-year-old children

In Study III, total body and abdominal adiposity were both significantly higher among children with low CRF than those with moderate or high CRF, even controlling for age, sex, and BMI. These results are supported by previous cross-sectional and longitudinal studies that show an inverse relationship between CRF and weight status in children, as assessed with a variety of methods (Johnson et al. 2000; Koutedakis et al. 2005; Byrd-Williams et al. 2008; Lang et al. 2018; Lang et al. 2019).

In addition, even within the same BMI category, total body and abdominal adiposity were significantly higher in the low CRF group than the moderate and high CRF groups, among both healthy weight and overweight/obese children. These findings—that there exist significant inverse associations between CRF and accurately measured total body and abdominal adiposity among healthy weight and overweight/obese children—are important, as adiposity and especially abdominal adiposity are associated with cardiometabolic risks, even in childhood (Kelishadi et al. 2015; Jin et al. 2020). Having moderate to high levels of CRF may attenuate the harmful metabolic consequences caused by total and abdominal adiposity, even without changes in weight status (Ortega et al. 2018b); thus, higher CRF levels in children may be a key element in the prevention and reduction obesity-related health risks.

6.5 Muscular fitness is associated with total body and abdominal adiposity in eight-year-old children

In Study IV, inverse associations were found between MF and total body and abdominal adiposity in both sexes. These results are consistent with and expand on previous findings of associations between MF and obesity as a health outcome in which obesity was generally assessed using BMI and abdominal obesity was assessed by WC (Ortega et al. 2008; Smith et al. 2014; Thivel et al. 2016; García-Hermoso et al. 2019). In addition, regardless of BMI category, higher MF was associated with lower total and abdominal adiposity. That is, overweight and obese children with higher MF had significantly lower total and abdominal adiposity than children with lower MF in the same BMI category; a similar association was observed among healthy weight children. These findings are important, as adiposity and especially increased abdominal adiposity (as measured by DXA) have been shown to be independently associated with increased cardiometabolic health risk in obese children and adolescents (Jin et al. 2020). Less is known about the effect of MF on children; specifically, it is unclear whether higher levels of MF can counteract the adverse health effects of obesity (Ortega et al. 2018a). Study IV also examined the associations between MF and adiposity after adjusting for CRF and BMI; when CRF was taken into account, children with higher MF had lower total body adiposity than children with lower MF, but no statistically significant differences were found in abdominal adiposity between MF groups. Further follow-up studies of children using sophisticated methods of body composition measurement are needed to determine whether higher MF contributes to lower total and abdominal adiposity and whether higher MF counteracts the negative health consequences of obesity, independent of CRF.

6.6 Methodological considerations

The main strength of the population-based cross-sectional studies (Studies II, III, and IV) are that DXA was used to measure children's adiposity. DXA allowed more accurate measures of total body and abdominal adiposity than using only proxy measures like BMI or WC (Cossio Bolaños et al. 2019; Orsso et al. 2020). Another strength is that all the participating children were born in the same year and randomly drawn from a population register of the entire age group. There were as many girls as boys among participating children, and the distribution of IOTF-defined healthy weight, overweight, and obese children in the sample was representative of their age group, based on another study in Tampere (Vuorela et al. 2011).

Participation in the population-based cross-sectional research project was voluntary, and the families involved in the study may have been more positive about the subject of the research, which may have influenced the results. In addition, the cross-sectional nature of the data presents relationships between the chosen variables and limits the ability to determine causality in the results. Longitudinal and interventional studies performed on larger samples and using accurate adiposity assessments are needed to confirm the influence of FMS, CRF, and MF on total body and abdominal adiposity in children over time.

In Study II, the TGMD-2 test battery was used to assess children's FMS. It was chosen because it is a valid, reliable, and process-oriented assessment of FMS in young children (i.e., those aged 3–10). The TGMD-2 assesses two dimensions of gross motor performance: six locomotor skills (run, horizontal jump, slide, gallop, leap, and hop) and six object control skills (strike, basketball dribble, throw, catch, kick, and underhand roll) and all the FMS in the TGMD have between three and five performance criteria (Ulrich 2000; Goodway et al. 2019). In the present study, due to time and space limitations at the research site, three locomotor skills (gallop, leap, and horizontal jump) and two object control skills (stationary dribble and overhand throw) were chosen. Intra-observer reliability tests were conducted with 24 children in the pilot study before the assessments of the main study. All the children were videotaped performing two trials of each task, and 25% of the children, selected at random, and all unclear cases were later double-checked on the videotape by the assessor.

In Study III, CRF was assessed indirectly using the 20 m SRT. The maximal oxygen consumption (VO_2 max) is generally considered the best indicator of CRF; it can be estimated using maximal or submaximal tests and direct or indirect methods (Raghuveer et al. 2020). However, in epidemiological studies concerning children, the most widely used test for assessing CRF is the 20 m SRT or modifications thereof (Tomkinson et al. 2019b). The reliability and validity of the 20 m SRT for determining VO_2 max in children have been widely documented, and the test has been used in children as young as six years old (Tomkinson et al. 2003; Tomkinson et al. 2019b). In addition, the 20 m SRT is recommended for young children because it requires limited skill and habituation.

In Study IV, field tests were used to determine MF. Field tests provide comparable data to laboratory-based tests in the assessment of overall MF in children, including children with overweight and obesity (Thivel et al. 2016). MF was assessed with three tests that measure middle and upper body strength and endurance and are recommended in the FitnessGram HRF test battery for assessment of MF in children and youth. The FitnessGram is a valid, reliable, practical, and widely used field test battery for assessing HRF (Plowman 2013; Kolimechkov 2017).

6.7 Practical implications and future directions

As the childhood years are important for building health-related habits and learning and improving FMS, the findings of this study have practical implications for researchers, policymakers, healthcare personnel, school management organizations and teachers working in primary school settings, and parents.

The main findings of this study highlight that accurately assessed total body adiposity and abdominal adiposity are significantly inversely associated with FMS, CRF, and MF in eight-year-old children. In addition, regardless of BMI category, better CRF and MF were associated with lower total and abdominal adiposity in eight-year-old children. These findings are important, as CRF and MF may attenuate the harmful cardiometabolic consequences caused by obesity and thus may join a healthy diet as key elements in the prevention of obesity and obesity-related health risks in childhood. It is important to encourage all children, and especially overweight and obese children, to take part in play and activities that enhance both CRF and MF.

Early childhood education and primary schools should be understood as a powerful settings for promoting a healthy lifestyle among children, as teachers and school health personnel can play an important role by identifying children with unhealthy weight status and encouraging children to engage in activities that enhance FMS, CRF, and MF. Special attention should be paid to overweight and obese children with lower FMS, CRF, and MF by encouraging children to learn a wide range of FMS and to engage in activities that enhance CRF and MF.

The importance of teaching FMS should be emphasized in early childhood education and primary school teacher studies. Attention, learning opportunities, quality teaching, and encouragement are all needed to promote various FMS among all children, but especially those with overweight and obesity. The risk of being overweight at the age of eight years appears to start very early (Glavin et al. 2014), and the critical time for learning FMS is before school age; thus, attention should be paid even before children reach that age and should be maintained at the beginning of the primary school years.

Based on the findings and practical experience gained in this study, a few suggestions can also be offered to researchers. Future studies should pay attention to measuring children's CRF and MF levels and their association with accurately assessed total body and abdominal adiposity, because excess abdominal and total body adiposity, despite normal BMI, have been shown to be associated with cardiometabolic dysfunction (García-Hermoso et al. 2020; Gómez-Zorita et al. 2021). Moreover, researchers in the field should examine the associations separately in girls and boys, as DXA-measured body composition differed significantly between sexes in the present study. In research settings, it would be appropriate to assess children's FMS with tests that assess the observable process and quality of movement. Process-oriented tests for FMS assessment provide qualitative information on the characteristics or quality of movement patterns and allow researchers to identify a child's developmental skill level rather than their physical growth or maturational status. FMS measurements should be harmonized so as not to interfere with fitness measurements. In addition, the terminology concerning FMS should be unified, and measurement of FMS needs more internationally standardized methods to enable better comparison of results between studies. In the future, studies with larger research populations and children of different ages could increase the generalizability of the findings of this study. In addition, longitudinal and long-term intervention studies beginning in the early childhood years would help researchers gain a better understanding of the nature of the relationships between FMS, HRF, and adiposity. Today, research examining FMS with accurate methods for assessing adiposity remains scarce. Future research should assess weight status using multiple methods that are more accurate than only BMI to obtain more precise evidence for the relationship between FMS performance and health in children. BMI is an easy method to use but does not differentiate between fat mass and FFM or provide information on the distribution of adipose tissue. Further, from the educational point of view, it would be valuable to find out whether kindergarten and primary school teachers need more knowledge and skills to plan physical education classes that support FMS learning among children with lower FMS.

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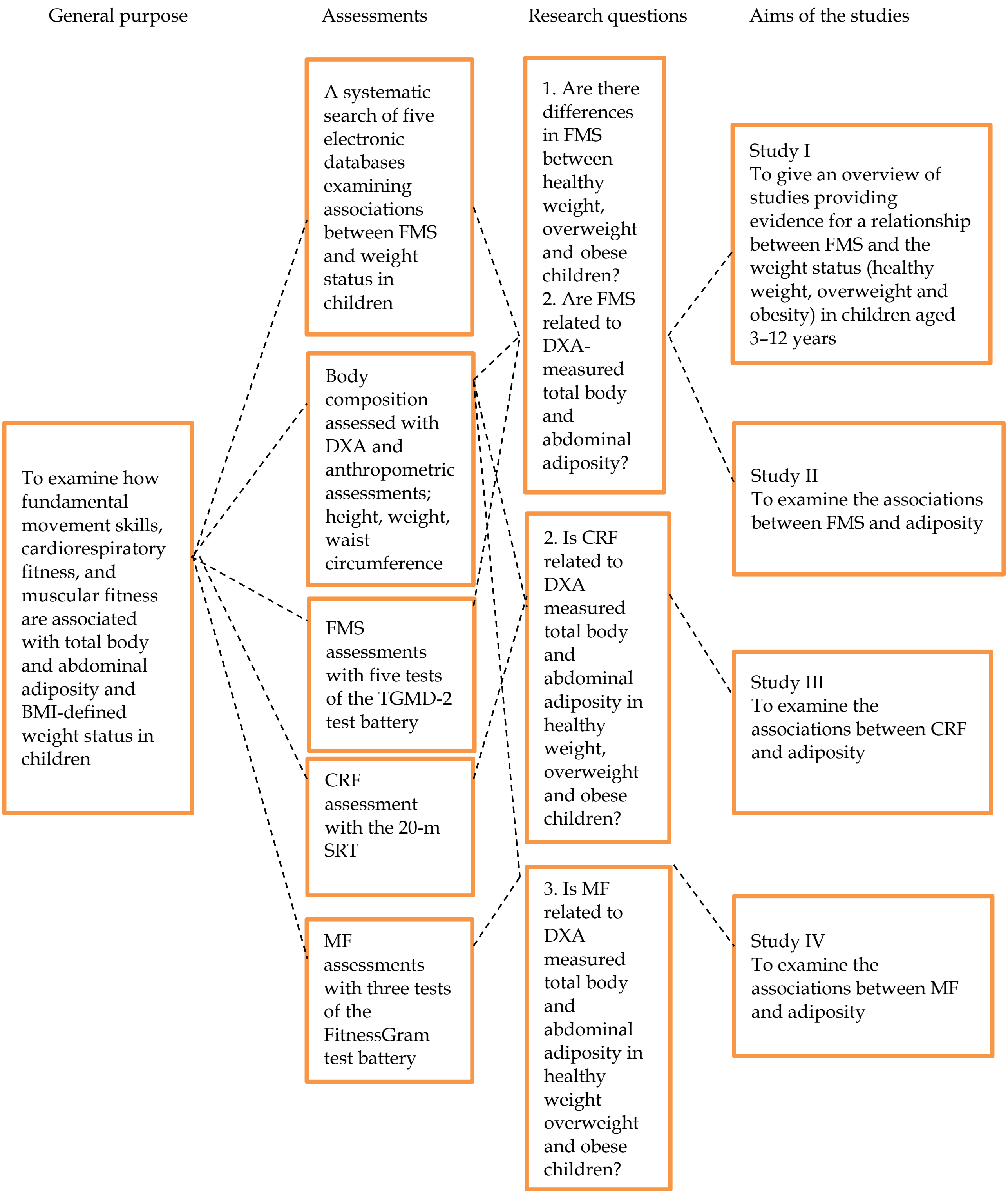
APPENDICES

Appendix 1. General purpose, assessments, research questions and aims of the studies



Appendix 2. IOTF international cut off points for body mass index for overweight and obesity by sex between 2 and 18 years, defined to pass through body mass index of 25 and 30 kg/m^2 at age 18 (Cole et al. 2000)

Age	Body mass index 25 kg/m2		Body mass index 30 kg/m2	
	Males	Females	Males	Females
2	18.41	18.02	20.09	19.81
2.5	18.13	17.76	19.80	19.55
3	17.89	17.56	19.57	19.36
3.5	17.69	17.40	19.39	19.23
4	17.55	17.28	19.29	19.15
4.5	17.47	17.19	19.26	19.12
5	17.42	17.15	19.30	19.17
5.5	17.45	17.20	19.47	19.34
6	17.55	17.34	19.78	19.65
6.5	17.71	17.53	20.23	20.08
7	17.92	17.75	20.63	20.51
7.5	18.16	18.03	21.09	21.01
8	18.44	18.35	21.60	21.57
8.5	18.76	18.69	22.17	22.18
9	19.10	19.07	22.77	22.81
9.5	19.46	19.45	23.39	23.46
10	19.84	19.86	24.00	24.11
10.5	20.20	20.29	24.57	24.77
11	20.55	20.74	25.10	25.42
11.5	20.89	21.20	25.58	26.05
12	21.22	21.68	26.02	26.67
12.5	21.56	22.14	26.43	27.24
13	21.91	22.58	26.84	27.76
13.5	22.27	22.98	27.25	28.20
14	22.62	23.34	27.63	28.57
14.5	22.96	23.66	27.98	28.87
15	23.29	23.94	28.30	29.11
15.5	23.60	24.17	28.60	29.29
16	23.90	24.37	28.88	29.43
16.5	24.19	24.54	29.14	29.56
17	24.46	24.70	29.41	29.69
17.5	24.73	24.85	29.70	29.84
18	25	25	30	30

ORIGINAL PAPERS

I

FUNDAMENTAL MOVEMENT SKILLS AND WEIGHT STATUS IN CHILDREN: A SYSTEMATIC REVIEW

by

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REVIEW

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

Fundamental movement skills and weight status in children: A systematic review

Sari Slotte[1, 2 ABDEFG], Arja Sääkslahti[1 ADEF], Katriina Kukkonen-Harjula[2, 3 ADE], Pauli Rintala[1 ADE]

[1] Faculty of Sport and Health Sciences, University of Jyväskylä, Finland

[2] The UKK Institute for Health Promotion Research, Tampere, Finland

[3] South Karelia Social and Health Care District, Lappeenranta, Finland

abstract

Background Obesity has become a major health challenge in children. Fundamental movement skills (FMS) are suggested to have an important role for being physically active and decreasing the risk of obesity. This systematic review aimed to give an overview of studies providing evidence for a relationship between FMS and the weight status in children.

Material/Methods A systematic search of five electronic databases (MEDLINE (PubMed), SportDiscus, ERIC, PsycInfo and SCOPUS) was conducted in January 2015. Studies examining associations between FMS and weight status in children aged 3–12 years were included.

Results The final sample included 12 cross-sectional studies. Seven studies found statistically significant inverse association between FMS and body mass index (BMI). Three studies used waist circumference (WC), and significant inverse associations were found in two of these. Dual-energy X-ray absorptiometry (DXA) was used in one study and significant association was found between FMS and abdominal and total body fat percentage. One study, using skinfolds, found no association.

Conclusions Based on the findings of the 12 studies, the relationship between FMS and weight status in children aged 3–12 years remains unclear. Developing competency in FMS may have important health consequences, and more studies are needed in which body composition is objectively measured with DXA.

Key words BMI, fundamental movement skills, motor skills, obesity, overweight, weight status

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Corresponding author: Mrs. Sari Slotte, University of Jyväskylä – Faculty of Sport and Health Sciences P.O. Box 35 (L), FI-40014 University of Jyväskylä , Jyväskylä FI-40014, Finland; e-mail: sari.a.slotte@jyu.fi

INTRODUCTION

Among children and adolescents, obesity has substantially increased worldwide. A recent systematic review indicated that between 1980 and 2013, the prevalence of overweight or obese children and adolescents (ages 2–19 years) increased by nearly 50%. In 2013, approximately 23% of girls and 24% of boys living in developed countries and 13% of girls and 8% of boys in developing countries were found to be overweight or obese [1]. Obesity is associated with multiple physical and psychological health problems already in childhood as well as with co-morbidities later in life [2]. Because of the established health risks and substantial increases in prevalence, obesity has become a major global health challenge [1].

The observed increase in the prevalence of childhood overweight and obesity is a likely consequence of a change in physical activity (PA) and nutrition patterns over time [3]. Adequate PA, together with healthy weight, is a protective factor against many health problems. PA has beneficial effects on adiposity, musculoskeletal health and fitness, and several components of cardiovascular health in children and adolescents [4]. Moreover, data from observational studies indicate dose-response relationships – the more PA, the greater the health benefits, and results from intervention trials show that even modest amounts of PA can have health benefits in obese youth [4].

Overall, low levels of PA are a potential cause and consequence of obesity, and it has been hypothesized that poor competence in fundamental movement skills (FMS) may be an important factor in this process. Low levels of PA lead to weight gain and a further reduction in PA because obesity may restrain the development of FMS and further decrease the motivation to participate in physical activities, which in turn increases weight gain [5–8].

FMS are an important part of human life, and they are interrelated with a child's physical, cognitive and social development [9]. FMS are considered to be the building blocks for movement and provide the foundation for specialized and sport-specific motor skills required for participation in a variety of physical activities. FMS are categorized as locomotor (e.g. run, hop, jump, leap), object-control (e.g. throw, catch, kick, strike), and stability (dynamic and static balance) skills [6]. Although motor development is a process continuing throughout life, early childhood is the optimal phase to learn and develop FMS [6]. This development is established through an interactive process of aspects related to the individual, the task and the environment. These aspects include biological and demographic factors, behavioral attributes and skills, cognitive, emotional and psychological factors, cultural and social factors and physical environmental factors [10].

Despite increasing interest in recent years in childhood overweight and obesity and their relationship to health-related fitness and motor competence, the association between weight status and FMS has not been comprehensively examined. Earlier reviews have examined associations of FMS competency with potential psychological, physiological and behavioral health benefits [11], between motor competence and health-related physical fitness [12], and motor competence and its effect on positive developmental trajectories of health [7]. In those reviews, assessments describing and defining motor skills varied and fitness components other than solely FMS were also measured.

The purpose of this systematic review was to give an overview of studies providing evidence for a relationship between FMS performance and weight status (healthy weight, overweight and obesity) in children.

MATERIAL AND METHODS

IDENTIFICATION OF STUDIES

A systematic search of five electronic databases (MEDLINE (PubMed), SportDiscus, ERIC, PsycInfo and SCOPUS) was conducted in January 2015 by an experienced informatician. Key words included motor skill, movement skill, fundamental movement skills, object control skill, locomotor skill, motor competence, motor proficiency, motor ability, obesity, overweight, weight status, body mass index, BMI, body composition, waist circumference, body fat, fatness, children, child, youth, kindergarten, and preschool children. The searches were conducted using single and combined terms. Only articles published in English in reviewed journals were considered for review.

CRITERIA FOR INCLUSION AND EXCLUSION

Titles and abstracts of the potentially relevant references were checked after removal of duplicates and then the full-text copies of potentially relevant citations were obtained. Then the two authors (SS and AS) independently reviewed the full-text articles and assessed the eligibility of the studies for inclusion (Figure 1). The inclusion criteria were the following: (a) participants were aged 3–12 years; (b) at least two FMS were assessed and the FMS measurement used was identified as a process- or product-oriented measurement; (c) a summary of FMS performance (reported as a total FMS score, object control score or locomotor score) was included in the analysis; (d) a quantitative analysis of the relationship between FMS and weight status were found; (e) only gross motor skills were assessed and a fine motor skills score was not included in analyses; and (f) the study was published in peer-reviewed journals in English. This review did not include studies with special populations or subjects with underweight, intervention studies or studies that evaluated only overweight/obese children/adolescents, fine motor skills, health-related fitness or motor abilities. If there was uncertainty about including an article, the article in question was reviewed again together by two of the authors (SS and AS) until a final decision was made. Ultimately, 14 unique citations met the eligibility criteria (Table 1).

Table 1. Summary of studies of the association between FMS competency and weight status

	Study Country	Sample Age/school grade	Analyses	FMS measure	Obesity measure	Results
1.	Franjko et al. 2013 (14) Croatia	73 children 8y	Pearson product-moment correlations	PROCESS: TGMD-2 PRODUCT:The FMS-POLYGON	BMI (?) Skinfolds (triceps and calf)	No statistically significant correlations between BMI and FMS in the total sample, nor in the separate sample of girls and boys. Significant relationships between BF and FMS were found in the total sample and in the sample of eight-year-old girls.
2.	D'Hondt et al. 2009 (23) Belgium	117 children 5-10 y	ANOVA, bivariate correlation	PRODUCT: MABC	BMI (IOTF)	FMS competency (ball skills and balance) was higher in normal and overweight compared with obese children

	Study Country	Sample Age/school grade	Analyses	FMS measure	Obesity measure	Results
3.	Hume et al. 2008 (27) Australia	248 children 9-12 y	Linear regression, bivariate correlation	PROCESS: A Manual for Classroom Teachers. Object control and locomotor	BMI (IOTF)	BMI not associated with FMS in boys or girls. Compared with overweight or obese children, a higher proportion of children classified as non-overweight achieved mastery/near mastery in running.There were no differences in the other skills according to weight status or in the total FMS, object-control, or locomotor proficiency scores.
4.	Kemp & Pienaar 2013 (21) South Africa	816 children 6.84 (+0.39 SD)	Correlation coefficient?	PROCESS: TGMD-2 (only object control) PRODUCT: Bruininks Oseretsky test of Motor Proficiency-2	BMI (IOTF) values: normal weight, oveweight, obese) Skinfolds (subscapular, triceps, calf) Waist circumference	No significant correlations between obesity measures and object control skills. Small significant correlation between balance and BMI, running speed/ agility and BMI and body fat %.
5.	Khalaj & Amri 2014 (15) Iran	160 children 4-8 y	ANOVA	PROCESS: TGMD-2	BMI (IOTF)	Obese children had lower gross motor skill proficiency compared to their normal weight peers. 6-8 y obese children performed poorer gross motor skills compared to 4-6 y obese children
6.	Logan et al. 2011 (16) USA	38 children 4-6 y	Pearson product-moment correlations	PRODUCT: MABC-2	BMI (CDC)	No significant relationship existed between MABC-2 and BMI percentile ranks (r = -.237). Significant differences in MABC-2 percentile ranks existed between high and low (p = .042), and high and medium (p = .043) groups.
7.	Morano et al. 2011 (24) Italy	80 children 4.5±0.5 y	ANOVA Pearson's product-moment correlations	PROCESS: TGMD-2	BMI (IOTF) Overweight/non-oveweight	Relationships (p < 0.001) between BMI and locomotor and object-control skills, and between BMI and the Gross Motor Development Quotient. Overweight participants showed poorer performance on locomotor and object-control tasks than their non-overweight peers.
8.	Nervik et al. 2011 (25) USA	50 children 3-5 y	Pearson chi-square static test Pearson correlation coefficient test Stepwise hiearchical regression analysis	PRODUCT: PDMS-2	BMI percentiles / weight categories (CDC growth charts): 1)non-overweight or non-obese 2) overweight or obese	A significant correlation between BMI sets and gross motor quotients category (P=.002). BMI and the continuous measure of gross motor score not significant.
9.	Okely et al. 2004 (20) Australia	4363 children and adolescents 4, 6, 8, 10 grades	Logistic regression modelling, multiple linear regression	PROCESS: A Manual for Classroom Teachers	BMI (IOTF) Waist circumference	Overall FMS proficiency and locomotor skill proficiency were inversely associated with BMI and WC in children. No association between object control skill proficiency and BMI.
10.	Roberts et al. 2012 (17) USA	4650 children 4-6 y	ANOVA	PRODUCT (?): Combination of individual gross motor items from the Early Screening Inventory Revised, The Early Childhood Longitudinal Study Kindergarten Cohort of 1998-1999, The Bruininks-Oseretsky Test of Motor Proficeincy, and The MABC	BMI percentiles / weight categories (CDC growth charts):	Children with obesity had decreased motor abilities compared with children in other weight categories. There was no difference in skill level between weight categories for a manipulative task or involving body mass mobilization or management.
11.	Southall et al. 2004 (26) Australia	142 children 10.8 y	ANCOVA	PROCESS: TGMD-2	BMI (IOTF)	Overweight children had lower total FMS and locomotor FMS. No difference between overweight and normal weight children for object control skills.
12.	Spessato et al. 2012 (28) Brazil	178 children 4-7 y	ANOVA Pearson's correlations Regression analysis	PROCESS: TGMD-2	BMI percentiles / weight categories (CDC growth charts):	No differences in motor competence between obese and nonobese for the overall sample.
13.	Spessato, Gabbard &Valentini 2013 (29) Brazil	264 children 5-10 y	ANOVA Pearson's correlations Linear regression analysis	PROCESS: TGMD-2	BMI (CDC)	BMI was not significantly correlated with motor competence (overall, locomotor or object control). The linear regression model indicated that overall MC was a better predictor of PA than BMI.
14.	Slotte et al. 2015 (22) Finland	304 8 y	ANOVA	PROCESS: TGMD-2	Total body fat %, abdominal fat % (DXA) BMI (IOTF) Waist circumference	Significant inverse correlations between all the FMS categories (object control, locomotor and total FMS) and the different weight status variables (BF%, AF%, WC and BMI) measured.

CRITERIA FOR ASSESSMENT OF STUDY QUALITY

Two authors (KK-H and PR) independently assessed the quality of the 14 eligible studies (Table 2). The criteria for assessing the quality of the studies were adopted from Lubans et al. [11] based on the STROBE [13] and CONSORT [14] statements. A quality score for each study was completed on a six-point scale by assigning a value of 0 (absent or inadequately described) or 1 (explicitly described and present) to each of the following questions listed: (a) Did the study describe the participants' eligibility criteria? (b) Were the participants randomly selected? (c) Did the study report the details of FMS assessment and did the instruments have acceptable reliability for the specific age group? (d) Did all of the methods have acceptable reliability? (e) Did the study report a power calculation and was the study adequately powered to detect hypothesized relationships? (f) Did the study report the numbers of individuals who completed each of the different measures and complete at least 80% of them? Studies that scored 0–2 were classified as low quality, 3–4 as medium quality and 5–6 as high quality.

Table 2. Assessment of Study Quality of the 14 studies

	1. Did the study describe the participants' eligibility criteria?	2. Were the participants randomly selected?	3. Did the study report the details of FMS assessment and did the instruments have acceptable reliability for the specific age group?	4. Did all of the methods have acceptable reliability?	5. Did the study report a power calculation and was the study adequately powered to detect hypothesized relationships?	6. Did the study report the numbers of indivi duals who completed each of the different measures and complete at least 80% of them?	Total quality score/ max 6
D'Hondt et al. 2009 (23)	0	0	1	1	0	1	3
Franjko et al. 2013 (14)	0	1	1	0	0	0	2
Hume et al. 2008 (27)	1	1	1	1	0	1	5
Kemp & Pienaar 2013 (21)	1	1	0	1	0	1	4
Khalaj & Amri 2014 (15)	0	0	1	1	0	0	2
Logan et al. 2011 (16)	1	0	0	1	0	1	3
Morano et al. 2011 (24)	0	0	1	1	0	1	3
Nervik et al. 2011 (25)	1	0	1	1	0	1	4
Okely et al. 2004 (20)	1	1	1	1	0	1	5
Roberts et al. 2012 (17)	1	1	0	1	0	1	4
Southall et al. 2004 (26)	1	1	1	1	0	1	5
Spessato et al. 2012 (28)	1	0	1	1	0	1	4
Spessato et al. 2013 (29)	1	0	1	1	0	1	4
Slotte et al. 2015 (22)	1	1	1	1	0	1	5

CATEGORIZATION OF VARIABLES AND LEVEL OF EVIDENCE

The relationship between FMS performance and weight status was determined by examining the percentage of studies that reported a statistically significant relationship (Table 3). Results were coded using the method earlier used by Lubans et al. [11] with the following criteria adopted: (a) Lack of scientific evidence if less than 33% of the studies indicated a significant association between variables or none of the studies deemed as low risk of bias found a significant association; (b) Uncertain evidence if 34–59% of the studies indicated a significant association between variables and at least one of them was deemed low risk of bias; (c) Positive evidence if 60–100% of the studies indicated a significant association between variables and 34–59% of the studies deemed low risk of bias found a significant association (in the same direction); (d) Strong evidence if 60–100% of the studies indicated a significant association between variables (in the same direction) and more than 59% of the studies deemed low risk of bias (score ≥5) found a significant association.

Table 3. Summary of studies examining the relationship between weight status and FMS

Weight status	Associated with FMS		Not associated		Summary coding (a) n/N for study		Association (b)	Level of evidence (c)
	testscore	references	testscore	references	(%)	high quality		
BMI	7	(17, 20, 22-26)	5	(16, 21, 27-29)	7/12 (58)	3/12	inverse	?
WC	2	(20, 22)	1	(21)	2/3 (67)	2/3	inverse	++
skinfolds			1	(21)	0/1 (0)	0/1	no	0
DXA	1	(22)			1/1 (100)	1/1	inverse	++
	Associated with product-oriented		Not associated					
BMI	3	(17, 23, 25)	1	(16)	3/4 (75)	0/4	inverse	0
WC								
skinfolds								
DXA								
	Associated with process-oriented		Not associated					
BMI	4	(20, 22, 24, 26)	4	(21, 27-29)	4/8 (50)	3/8	inverse	?
WC	2	(20, 22)	1	(21)	2/3 (67)	2/3	inverse	++
skinfolds					0/1 (0)	0/1	no	0
DXA	1	(22)	1	(21)	1/1 (100)	1/1	inverse	++
	Associated with locomotor skills		Not associated					
BMI	6	(17, 20-22, 24, 26)	2	(27, 29)	6/8 (75)	3/8	inverse	+
WC	2	(20, 22)			2/2 (100)	2/2	inverse	++
skinfolds								
DXA	1	(22)			1/1 (100)	1/1	inverse	++
	Associated with object control skills		Not associated					
BMI	3	(22-24)	5	(20, 21, 26, 27, 29)	3/8 (38)	1/8	inverse	?
WC	1	(22)	2	(20, 21)	1/3 (33)	1/3	inverse	0
skinfolds			1	(21)	0/1 (0)	0/1	no	0
DXA	1	(22)			1/1 (100)	1/1	inverse	++
	Associated with stability skills		Not associated					
BMI	2	(21, 23)	1	(17)				
WC					2/3 (67)	0/3	inverse	0
skinfolds								
DXA								

(a) An overall summary of the findings. n = number of studies that report support for relationship, N = number of studies that examined and reported possible associations between FMS and weight status.
(b) The direction of the association.
(c) 0 = Lack of scientific evidence, ? = Uncertain evidence, + = Positive evidence, ++ = Strong evidence

RESULTS

LITERATURE SEARCH

A total of 783 references were identified from five electronic databases. Initial screening of titles and abstracts produced 40 (SS) and 64 (AS) potentially relevant references after removal of duplicates. These references were further screened for their full text and 14 studies met the inclusion criteria (Figure 1).

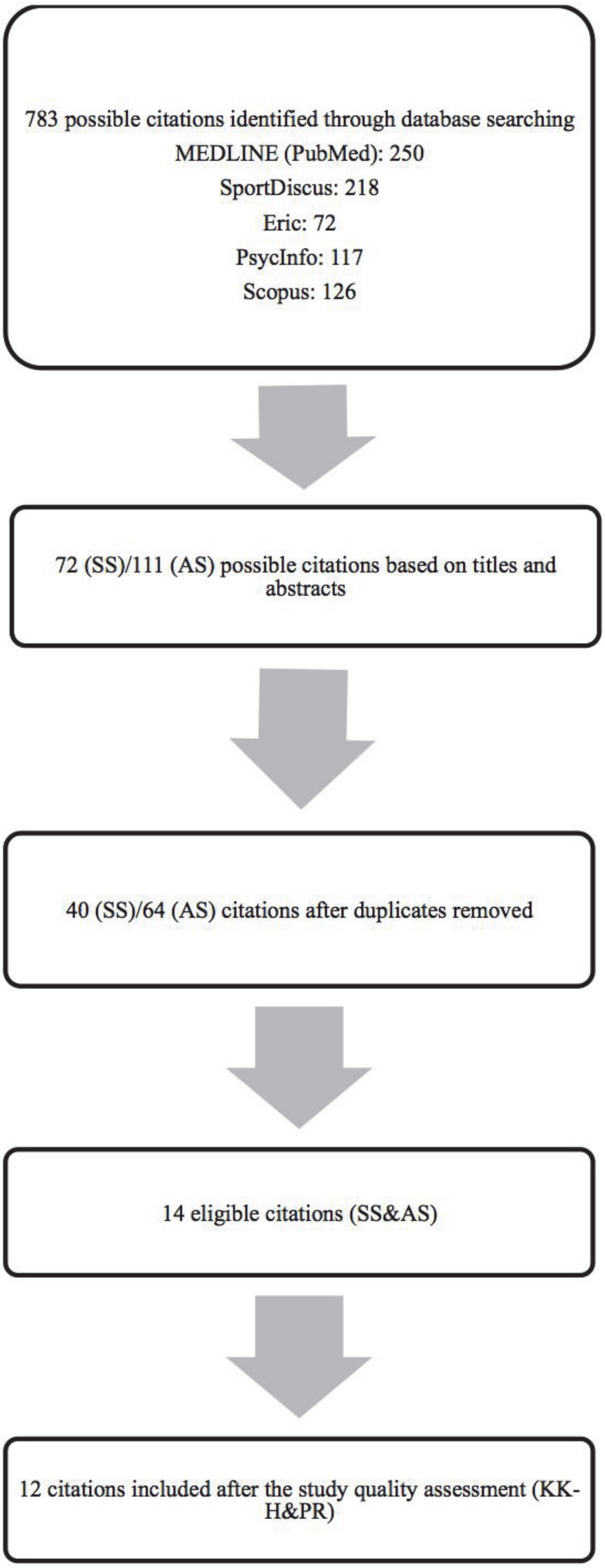

Fig. 1. Flow of studies through the systematic review process

STUDY QUALITY

Results from the assessment of study quality are reported in Table 2. Four of the studies were classified as high [21, 23, 27, 28], eight as medium [17, 18, 22, 24–26, 29, 30] and two of low quality [15, 16]. The low quality studies [15, 16] were excluded from analyses, and the final sample in this review included 12 studies.

OVERVIEW OF INCLUDED STUDIES

All the included studies were cross sectional and published between 2004 and 2014. Three of the studies were from Australia [21, 27, 28], three from Europe [23–25] (Belgium, Finland and Italy), three from the USA [17, 18, 26], two from South America [29, 30] (Brazil) and one from Africa [22] (South Africa). The number of study participants ranged from 38 [17] to 4650 [18]. All the studies examined associations between FMS and weight status using correlation and/or regression analyses.

WEIGHT STATUS

In all the studies weight status was established using the body mass index (BMI) calculated from weight and height. Seven studies (58%) used IOTF/Cole et al. [19] sex- and age-specific BMI cutoff values based on six internationally representative data sets. The US growth-curves from the Centre for Disease Control and Prevention (CDC) [20] were used in five studies (42%). In addition waist circumference (WC) was measured in three studies [22–24], skinfold thickness in one study [22] and dual energy X-ray absorptiometry (DXA) was used in one study to measure abdominal fat percentage and total body fat percentage [23].

FMS ASSESSMENT

In seven studies FMS performance was defined using process-oriented tests (i.e. qualitative movement patterns): the Test of Gross Motor Development-2 in five studies [23, 25, 26, 29, 30] and items from the Fundamental Motor Skills: A Classroom Manual for Teachers in two studies [21, 28]. In four studies FMS competency was defined using product-oriented tests (i.e. outcomes): the Movement Assessment Battery for Children in two studies [17, 24], the Peabody Developmental Motor Scales (second edition) in one study [26] and a combination of individual test items from the Early Screening Inventory Revised, the Early Childhood Longitudinal Study Kindergarten Cohort of 1998–1999, the Bruininks–Oseretsky Test of Motor Proficiency, and the Movement Assessment Battery for Children in one study [18]. In one study FMS competency was defined using a combination of both process-oriented and product-oriented tests [22]: the Test of Gross Motor Development-2 and the Bruininks–Oseretsky Test of Motor Proficiency.

ASSOCIATION BETWEEN FMS AND WEIGHT STATUS

Seven (58%) studies found statistically significant inverse association between FMS total score and BMI [18, 21, 23–27]. Three of these were classified as high quality [21, 23, 27]. Five (42%) studies did not demonstrate statistically significant associations between FMS score and BMI [17, 22, 28–30], and one of these was classified as high quality [28]. Three studies used WC [21–23] and significant inverse associations were found in two of these studies [21, 23], classified as high quality. One study [22], which used skinfolds, found no statistically significant association. In one study DXA was used and a significant association was found between FMS and abdominal fat percentage and total body fat percentage [23].

ASSOCIATION BETWEEN TOTAL SCORES OF PRODUCT- AND PROCESS-ORIENTED TESTS AND WEIGHT STATUS

Four studies used a product-oriented test for assessing FMS performance [17, 18, 24, 26] and in three of them FMS were significantly inversely associated with weight status estimated using BMI [18, 24, 26]. None of these were classified as high quality.

Eight studies used a process-oriented test for assessing FMS performance [21–23, 25, 27–30]. All used BMI and significant inverse associations were found in four studies [21, 23, 25, 27] and three of them were classified as high quality [21, 23, 27]. Four studies did not find associations between FMS and BMI [22, 28-30], and one of these was classified as high quality [28]. Three studies also used WC [21–23] and a significant inverse association was found in two of these, both high-quality studies [21, 23]. In one study, classified as high quality, DXA was used and a significant association was found [23]. One study [22] which used skinfolds, found no association between FMS and weight status.

ASSOCIATION BETWEEN LOCOMOTOR SKILLS AND WEIGHT STATUS

Inverse association between locomotor skills and weight status was found in six studies [18, 21–23, 25, 27]: Kemp and Pienaar (product: running speed/ agility), Morano et al. (process: composite score of seven locomotor test tasks), Okely et al. (process: composite score of two locomotor test tasks), Roberts et al. (product: hop and jump), Southall et al. (process: composite score of six locomotor test tasks), Slotte et al. (process: composite score of three locomotor test tasks). Of these studies three were classified as high quality [21, 23, 27]. Two studies found no significant association between locomotor skills and weight status [28, 30]: Hume (process: composite score of two locomotor test tasks), and Spessato, Gabbard and Valentini (process: composite score of seven locomotor test tasks).

ASSOCIATION BETWEEN OBJECT-CONTROL SKILLS AND WEIGHT STATUS

Inverse association between object-control skills and weight status was found in three studies [23–25]: D'Hondt (product: ball skills), Morano (process: composite score of five object-control test tasks) and Slotte (process: composite score of two object-control test tasks), and one of these was classified as high quality [23]. In five studies there was no significant association between object-control skills and weight status [21, 22, 27, 28, 30] and three of these were classified as high quality [21, 27, 28].

ASSOCIATION BETWEEN STABILITY SKILLS AND WEIGHT STATUS

Inverse association between stability skills and weight status was found in two studies [22, 24] and in one study [18] the association was not significant. None of these were classified as high-quality studies.

DISCUSSION

FMS are natural part of human life and important for a child's physical, cognitive and social development. In addition, experiences support learning and development of FMS and the foundations of these skills are created in early childhood. It has been hypothesized that better FMS performance is essential to encourage a physically active lifestyle, which for its part leads to healthy weight status [5–8].

The purpose of this systematic review was to examine the relationship between FMS performance and weight status (healthy weight, overweight and obesity) in children aged 3–12 years. Overall there was an inverse but weak association between FMS and weight status. Seven (58%) of the studies found a statistically significant inverse association between FMS total score and BMI, and five (42%) studies found no association. In those studies using WC for establishing weight status, an inverse association was found in two of the three studies (67%) and in the one study, which used skinfolds, found no significant association. In one study DXA was used and a statistically significant inverse association was found between FMS performance and weight status.

Eight studies used process-oriented tests and four studies used product-oriented tests for assessing FMS. Half of the studies, which used process oriented tests and three of four studies which used product-oriented tests, found significant inverse association between FMS and weight status (BMI). Product-oriented (quantitative) assessment techniques evaluate the outcome of the movement skills and are based on the time, distance or number of successful attempts resulting from the performance of the skill but process-oriented (qualitative) assessment techniques evaluate the form of the movement skills [31]. Process-oriented assessments may be more suitable when assessing overweight and obese children because they more accurately identify specific characteristics of the movement, reflecting the developmental skill level instead of maturational levels and physical growth of children.

In those studies where FMS was partitioned into locomotor skills, object-control skills or stability, inverse associations between FMS proficiency and weight status were mostly found in locomotor skills rather than object-control skills or stability. It has been suggested that biomechanical factors associated with high body mass, such as lower limb problems, may be one reason that overweight and obese children have greater difficulty in performing locomotor skills [32, 33].

Based on this systematic review, the relationship between FMS and weight status in children is still unclear. This is contrary to the conclusions of the two earlier reviews [11, 12]. The explanation may be that assessment methods describing and defining motor skills varied and also components of health-related fitness (e.g. cardiorespiratory and muscular fitness) and motor ability (e.g. speed, power, explosive strength) were measured in those reviews. Motor skills are sometimes confused with fitness abilities but are different. In our review we wanted to restrict to FMS, which are the foundation movements for more complex and specialized skills required in various physical activities and everyday life from childhood years to later in life.

In all the studies body weight status was established using BMI. In addition, skinfold thickness was measured in one study [22], WC in three studies [22–24] and only in one study [23] DXA was used to measure abdominal fat percentage and total body fat percentage. As body fatness and specifically abdominal fatness are associated with less favorable cardiovascular risk factor status in children and adolescents [34], it is important to assess weight status using more accurate methods than only BMI in order to obtain more precise evidence for a relationship between FMS performance and weight status in children. BMI is based on weight and does not differentiate between fat mass (adipose tissue) and lean mass (mostly muscle tissue) and, therefore, it is an imperfect measure of either fatness or thinness. In children BMI correlates with fat mass more strongly among heavy (where fat mass makes up a larger proportion of weight) than among thin children [35]. So in thin children BMI is a better predictor of lean mass than fat mass. Both BMI and WC are proxy measures and should not be considered as accurate measures of total body or abdominal fat [36] comparable with the measurement of body composition by more sophisticated methods such as DXA. DXA can be used to evaluate childhood obesity and determine fat mass [37], and it has increasingly been suggested and used as a criterion or a reference method for comparing other measurements of body composition [38]. In most of the studies included, obese or overweight children were compared to those with healthy weight, while potential differences between healthy weight and underweight were not taken into consideration. There is lack of studies in underweight children and adolescents, and incomplete understanding of health consequences of underweight [39] and, therefore, a need for studies where underweight is included.

LIMITATIONS

This review has limitations. Longitudinal and intervention studies were not included in this review. The limitations of cross-sectional study designs prevent making definitive conclusions regarding causality relating to the development of FMS and weight status. The use of BMI as a measure of body weight status in all the studies in this review limits our understanding of the contributory effects of overall increased mass (i.e. body fat mass and lean mass) to FMS. One limitation is the fact that there were only 12 eligible studies on which our results are based on and the quality of the studies varied. Comparisons between studies were partly difficult due to the methodological heterogeneity and different methods used for assessing FMS performance and weight status. Our goal was to restrict the studies included to those, which clearly measured FMS, but some product-oriented tests likely evaluated motor abilities more than they did FMS.

CONCLUSIONS

The results of this systematic review indicate that the relationship between overall FMS proficiency and weight status in children aged 3–12 years is still unclear. However, the significant inverse relationship found between FMS proficiency and WC and especially with objectively measured abdominal fat percentage and overall body fat percentage, suggest that competency in FMS may have important health consequences.

There is a need for studies where body composition is more accurately measured with, for example, DXA. The use of BMI as an only measure of weight status limits the understanding of the contributory effects of overall increased mass (i.e. lean mass and body fat mass) to FMS. In addition, FMS should be assessed with qualitative tests, which focus on the technique of the movement. Also measurement of FMS needs more standardized and global methods. Research on FMS development and performance in developing children is scarce and rather dispersed and there is a shortage of updated information on movement skill development and performance especially in European children [40]. There are very few longitudinal studies in the area of childhood FMS, weight status and physical activity [41, 42] and longitudinal and long-term intervention studies from early childhood years would also better clarify the influence of FMS development on weight status. This kind of knowledge would help health care personnel and kindergarten and school physical education teachers to prevent development of overweight, and when needed, tailor intervention for individual needs.

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II

FUNDAMENTAL MOVEMENT SKILL PROFICIENCY AND BODY COMPOSITION MEASURED BY DUAL ENERGY X-RAY ABSORPTIOMETRY IN EIGHT-YEAR-OLD CHILDREN

by

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Fundamental movement skill proficiency and body composition measured by DXA in eight-year-old children

Sari Slotte[1, 2], Arja Sääkslahti[2], Jari Metsämuuronen[3], Pauli Rintala[2]

1 The UKK Institute for Health Promotion Research, Tampere, Finland

2 Department of Sport Sciences, University of Jyväskylä, Finland

3 Faculty of Behavioural Sciences, University of Helsinki, Finland

The study was completed at the UKK Institute for Health Promotion Research

Corresponding author: Sari Slotte

Faculty of Sport and Health Sciences

P.O. Box 35 (L), FI-40014 UNIVERSITY OF JYVÄSKYLÄ

Email sari.a.slotte@jyu.fi

Tel +358 50 511 7454

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Abstract

Objective: The main aim was to examine the association between fundamental movement skills (FMS) and objectively measured body composition using dual energy X-ray absorptiometry (DXA).
Methods: Study of 304 eight-year-old children in Finland. FMS were assessed with the Test of Gross Motor Development, 2nd ed. (TGMD-2). Total body fat percentage (BF%), abdominal region fat percentage (AF%), and fat-free mass (FFM) were assessed by DXA. Waist circumference, height and weight were measured and International Obesity Task Force (IOTF) cut-off values for BMI were used for the definition of healthy weight and overweight/obesity.
Results: Better FMS proficiency (object-control, locomotor, total FMS) was significantly and strongly associated with lower BF% and lower AF% measured with DXA.
Conclusions: The inverse association between FMS and body composition measured with DXA (BF% and AF%) is an important finding, as body fatness and specifically abdominal fatness are associated with less favourable cardiovascular risk factor status in children.

Keywords: Body composition, fundamental movement skills, DXA, motor skills, obesity, overweight

Introduction

With the increasing prevalence of overweight and obesity and inadequate levels of physical activity (PA) even in young children (Lobstein, Baur, & Uauy, 2004; Ness et al., 2007; de Onis, Blossner, & Borghi, 2010) there has recently been increased interest on potential links between motor development, PA behavior and obesity (Lubans, Morgan, Cliff, Barnett, & Okely, 2010). It has been hypothesized that children with better fundamental movement skills (FMS) have higher levels of health-related fitness and perceived motor competence, which in turn predict greater participation in PA and, consequently, healthier weight status (Stodden et al., 2008).

FMS are an important part of human life and are interrelated with a child's physical, cognitive and social development (Payne & Isaacs, 2002). In addition, PA experiences support the learning and development of FMS, which ideally should occur in early childhood, during the preschool and elementary school years (Gabbard, 2000; Gallahue, Ozmun, & Goodway, 2011). FMS are classified as locomotor, object-control and stability skills, and are a prerequisite for the more advanced and specific skills used in PA and sport. Moreover, failure to master FMS may hinder the development of specialised movement skills and create a barrier to participation in PA.

The results of studies on the association between FMS and weight status in children are still inconsistent even if the recent review (Lubans et al., 2010), which examined the relationship between FMS competency and potential psychological, physiological and behavioural health benefits in children and adolescents, concluded that there was an inverse association between FMS competency and weight status. The authors reported an inverse association in six studies and no association in three of the nine studies found. However, in one study inverse association was found only in boys but not in girls (McKenzie et al., 2002), in another study inverse association was found in total and locomotor FMS but not in object control skills between overweight and healthy weight children (Southall, Okely, & Steele, 2004) and in one study (Erwin & Castelli 2008) authors did not report association between weight status and FMS competency, even if that study was included in the list of studies which reported an inverse association. In most of the studies examining weight status and FMS, weight status was estimated using BMI only, and in one study waist circumference

(WC) was used (Okely, Booth, & Chey, 2004). BMI and WC are proxy measures of adiposity and should not be considered accurate measures of body fat (Freedman & Perry, 2000) comparable with the measurement of body composition by more sophisticated methods such as dual energy x-ray absorptiometry (DXA). DXA can be used to evaluate childhood obesity and determine fat mass (Helba & Binkowitz, 2009), and has increasingly being used as a criterion or reference for comparison with other measurements of body composition (Shypailo, Butte, & Ellis, 2008). Due to the relatively small number of studies and the inconsistency of the results there is need for studies of the association between FMS and weight status in children that rely on accurate measures of body composition. To our knowledge, no previous studies have analyzed the association between FMS and body composition measured with DXA.

The purpose of this study was to examine the association between FMS and body composition measured with DXA in eight-year-old children. A further aim was to investigate whether children differ in their FMS by weight status estimated using WC and BMI.

Methods

A random sample (n=750) of children born in 1997 and living in Tampere, Finland was drawn from the Population Register. Children and their parents were mailed an invitation to participate to the study. The participants were recruited and participated between October 2005 and July 2006 when the children were approximately eight years old (mean 8.6 y, range 8.2-9.2 y). All children and their parents were informed about the purpose and nature of the study and the measurements. All the children were accompanied by their mothers and both gave their written informed consent upon arrival at the research site. The current sample consisted of 304 children (151 girls, 153 boys) for whom complete data on FMS performance, DXA, BMI and WC were available. The study was approved by the Ethics Committee of Pirkanmaa Hospital District.

Height was measured to the nearest 0.1 cm and weight was determined using a high-precision electronic scale (F 150S-D2, Sartorius AG, Goettingen, Germany) to the nearest 0.1 kg, and the results of the measurements were used to calculate BMI (kg/m2). Participants were then classified as healthy weight, overweight or obese, according to the International Obesity Task Force (IOTF) cut-off points for age and sex (Cole, Bellizzi, Flegal, & Dietz, 2000) recommended by the European Childhood Obesity Group (ECOG) (Rolland-Cachera, 2011). Height and weight were measured in light clothing and without shoes. WC was measured in triplicate by a measuring tape, midway between the lowest rib and the superior border of the iliac crest. The average of the three WC measurements was used in all analyses. The total body fat percentage (BF%), abdominal region fat percentage (AF%) and fat free mass (FFM) of the participants were assessed with DXA (GE Lunar Prodigy Advance, GE Lunar Radiation Corp., Madison, WI). In addition, abdominal region fat, which includes intra-abdominal fat plus subcutaneous fat, was evaluated from a manually delineated region of interest that included the soft tissue area of the body between the lowest ribs and superior border of the iliac crest.

The test of Gross Motor Development-2 (TGMD-2) (Ulrich, 2000) was used to assess fundamental movement skills. The TGMD-2 is a valid, reliable and process-oriented assessment of gross motor development and is used in FMS research on young children between 3 and 10 years. The TGMD-2 assesses two dimensions of gross motor performance: locomotor and object-control skills. In the present study, three locomotor skills (gallop, leap, horizontal jump) and two object-control skills (stationary dribble, overhand throw) were evaluated. The test was administered in pairs or individually following standardized procedures, instructions and demonstrations (Ulrich, 2000).

The children were given a standardized visual demonstration of the correct technique for performing the skill before each test, but were not told what components were being assessed. All the children were videotaped performing two trials of each task, and the presence or absence of the designated criteria of form were evaluated by the assessor who has experience in FMS assessment as a PE teacher (researcher SS). 25% of randomly selected children and all the unclear cases were later double-checked on the videotape by the same assessor. In this study, intra-observer reliability tests were conducted with 24 children and Intraclass Correlation (ICC) for locomotor skill was 0.978 and for object-control skill 0.995. A correct performance was scored 1 and incorrect performance was scored 0. Each of the two trials was scored independently. The sum of the scores for the two performances represents the final score for each item. The correctly performed criteria for two trials each of the three locomotor and the two object-control skills were summed to provide subtest raw scores for locomotor skills (range 0 – 24 / 12 skill criteria) and object control skills (range 0 – 16 / 8 skill criteria). The raw scores (locomotor, object-control) were used in the data analysis as this is recommended for research purposes (Ulrich, 2000). In order to transform the sub-test raw scores into comparable final scores both sub-test raw scores were standardized to a maximum score of 16. The sum of both sub-tests yielded the total fundamental movement skill score (total FMS, range 0-32).

Means and standard deviations were calculated for all variables. Prior to analysis, normality and equality of variances of the groups were assessed using Kolmogorov–Smirnov test (with Lilliefors' correction) and Levene test, respectively. A one-way ANOVA was used to examine the differences in participant characteristics across the FMS groups. When the ANOVA result was significant ($p < 0.05$), a Tukey's post hoc comparison test was used to identify specific between-groups differences. When the variables were normally distributed, t-test and F-test were used. When the variables were shown to be non-normal, the Mann-Whitney U-test was used to test the difference between two groups, the Kruskal-Wallis test for differences between several groups and Spearman's rank-order correlation when assessing the associations between the variables. Exact p-values are reported for non-parametric statistics. Cohen's d was used as an indicator of the effect size (the values of Cohen's f were transformed to values of Cohen's d). The absolute value of the effect size is reported within the text; in the Tables, a negative value indicates that the higher value is subtracted from the lower value in the calculation procedure. Tukey's test was used in the post hoc analysis. Based on the test-performance, the children were assigned to three groups: low FMS (lowest third), moderate FMS (middle third) and high FMS (highest third). According to the IOTF cut-off points (Cole et al., 2000), children were classified as healthy weight, overweight or obese and then assigned to two categories, healthy weight or overweight/obese, for statistical analysis. All statistical analyses were undertaken using SPSS version 20.0 and the level of significance was set at $p = 0.05$.

Results

Of 304 children in the study, 80.9% were healthy weight (girls 81.4% and boys 80.4%) and 19.1% overweight/obese (girls 18.6% and boys 19.6%).

Descriptive statistics of the children by gender are shown in Table 1. In body composition, girls had a significantly bigger AF % ($p < 0.001$) and BF % ($p < 0.001$) than boys, although mean BMI was exactly the same. The effect sizes were medium or high (Cohen's d equals 0.59 and 0.66 respectively). When the FMS raw sub-test scores were examined by gender, boys were more proficient at object-control skills ($p < 0.001$, $d = 1.19$) and girls more proficient at locomotor skills ($p = 0.002$, $d = 0.36$). For total FMS, however, boys scored significantly higher ($p < 0.001$, $d = 0.70$).

--------------- Insert Table 1 about here ----------------

Descriptive statistics of the children by BMI group are shown in Table 2. In body composition, the overweight/obese children had significantly bigger AF % ($p < 0.001$, $d = 2.04$), BF % ($p < 0.001$, $d = 2.02$) and WC ($p < 0.001$, $d = 2.39$) than the healthy weight children. FMS proficiency was significantly lower among the overweight/obese children than healthy weight children in all the FMS categories: object-control skills ($p = 0.001$, $d = 0.49$), locomotor skills ($p < 0.001$, $d = 0.95$) and total FMS ($p < 0.001$, $d = 0.84$).

--------------- Insert Table 2 about here ----------------

The descriptive characteristics of boys and girls by low, moderate and high FMS groups are shown in Table 3. Among boys, BF % and AF % were statistically significantly higher in the low FMS group compared with the moderate and the high FMS groups. Also, the moderate FMS group differed significantly from the high FMS group. Among girls, BF % and AF % were statistically significantly higher in the low FMS group compared with the high FMS group. Among both genders, BMI, WC and weight were also higher in the low FMS group compared with high FMS group. There were no statistically significant differences in FFM or height between the FMS groups.

--------------- Insert Table 3 about here ----------------

The correlations between FMS and the different obesity variables in boys and girls are shown in Table 4. All the obesity variables (BF%, AF%, WC and BMI) were statistically significantly inversely correlated with FMS proficiency (object-control, locomotor and total FMS) among both genders. All the variables showed stronger correlations in boys than in girls. BF % was the strongest predictor of each of the FMS proficiency variables in boys. Among girls, object-control skills showed the strongest correlation with AF% and locomotor skills the strongest correlation with WC.

--------------- Insert Table 4 about here ----------------

Discussion

To our knowledge, this is the first study to examine the association between FMS proficiency and objectively measured body composition using DXA. The primary finding of the present study was that higher FMS proficiency was significantly and strongly associated with lower total body fatness and lower abdominal fatness measured with DXA in eight-year-old boys and girls. The inverse association between FMS and body composition measured with DXA (BF% and AF%) is an important finding, as body fatness and specifically abdominal fatness are associated with less favourable cardiovascular risk factor status in children (Daniels, Morrison, Sprecher, Khoury, & Kimball, 1999).

In addition, there were significant inverse correlations between all the FMS categories (object control, locomotor and total FMS) and the different weight status variables (BF%, AF%, WC and BMI) measured. These results are consistent and build on those of previous studies that have used only BMI or WC alone to estimate weight status (Lubans et al., 2010; Morano, Colella, & Caroli, 2011) indicating an inverse relationship between obesity and FMS proficiency. All the variables correlated more strongly in boys than in girls. BF % was the strongest predictor of each of the FMS proficiency variables in boys. Among girls, object-control skills showed the strongest correlation with AF% and locomotor skills the strongest correlation with WC.

Previous studies have suggested that differences in FMS proficiency between overweight/obese and healthy weight children are mostly due to differences in locomotor skills rather than object-control skills (Okely, Booth, & Chey, 2004; Southall, Okely, & Steele, 2004). For example, Southall et al., (2004) reported that while overweight children had significantly lower FMS proficiency, when FMS was partitioned into locomotor and object-control skills, the differences only existed for locomotor skills. Compared to these studies, FMS proficiency in our study was significantly lower among the overweight/obese children than healthy weight children in all the FMS categories: object-control skills, locomotor skills and total FMS, although the difference was more marked in locomotor skills and total FMS than in object control skills. These results agree with those of another European study (Morano et al., 2011) with younger children.

When FMS proficiency between the genders was examined, our findings are consistent with those of previous studies showing better locomotor skills among girls (Barnett, van Beurden, Morgan, Brooks, & Beard, 2008; Beurden, Zask, Barnett, & Dietrich, 2002; Hardy, King, Farrell, Macniven, & Howlett, 2010) and better object-control skills among boys (Barnett, van Beurden, Morgan, Brooks, & Beard, 2010; Hardy et al., 2010). In our study, the high effect size found for object-control skills is noteworthy, boys were markedly better than girls. Biology does not fully explain gender differences in the FMS proficiency of eight-year-old children. Gender differences are more likely socially and environmentally induced (Garcia, 1994; Hardy et al., 2010; Thomas & French 1985) and it would be important to encourage girls to practise object-control skills like kicking, throwing and catching. In fact, previous longitudinal studies have shown that children who had better object-control skill proficiency were more likely to become active and fit adolescents (Barnett et al., 2008; Barnett, van Beurden, Morgan, Brooks, & Beard, 2009).

When boys and girls were divided into tertiles - low FMS (lowest third), moderate FMS (middle third) and high FMS (highest third) - according to their test performance, increased BF%, AF%, WC and BMI were all correlated with poorer FMS results. Among both boys and girls the trend was very clear: the higher the children's FMS proficiency, the lower their body composition values. In fact, the boys in the Low FMS group had 8.6 % points more BF and 11.3 % points more AF than the boys in the High FMS group. In both cases, the differences are notable; the effect sizes were high (d = 1.11 and d = 0.99). The corresponding differences in girls' groups were 4.1 % and 7.1 % points. The differences are moderate; effect sizes were of medium size (d = 0.58 and d = 0.64).

The main strengths of this study were that DXA was used to measure body composition, all the children were within a narrow age range and mastery of FMS was double-checked afterwards on the videotape by the assessor. A limitation of this cross-sectional research is that the direction of the relationship between body composition and FMS proficiency cannot be determined. No conclusion can be drawn whether obesity in early childhood leads to poorer FMS development or whether children will become obese because of their lower FMS level, both of which possibilities may act as a barrier to PA participation. As both causal hypotheses are possible, longitudinal research would be needed to gain a better understanding the nature of the relationships between FMS, PA and body composition.

Because FMS are prerequisites of PA, it is important to support FMS development in young children. The recent meta-analyses provide evidence for the effectiveness of motor skill interventions to improve FMS in children (Logan, Robinson, Wilson, & Lucas, 2011; Morgan et al., 2013), however there is limited knowledge of effective strategies to promote long-term PA participation among overweight and obese children (Cliff, Okely, Morgan, Jones, & Steele, 2010). In addition, one longitudinal study (D'Hondt et al., 2014) found that children's weight status negatively influenced future level of gross motor coordination, and vice versa but total PA at baseline was not significantly related to motor skill performance nor BMI. It has been suggested that the first eight years of life would be the best time to learn FMS (Gallahue et al., 2011).

However, the development of FMS does not happen by chance or maturation alone; children also need opportunity and guidance within a supportive learning atmosphere. Although children should be provided with opportunities to practise FMS during free play, evidence indicates that teacher-directed activities lead to greater improvements in children's FMS proficiency (Deli, Bakle, & Zachopoulou, 2006). Moreover children require quality instruction, not just exposure to equipment and practice opportunities to develop appropriate FMS proficiency (Wall, Rudisill, Parish, & Goodway, 2004). Especially overweight and obese children should be given the opportunity to practice the entire range of motor skills in a motivational and supportive atmosphere with quality teaching (Morgan, Okely, Cliff, Jones, & Baur, 2008).

Conclusion

Our findings suggest that FMS proficiency (object-control, locomotor, total FMS) is inversely associated with body composition measured with DXA (BF% and AF%) and weight status estimated using WC or BMI in eight-year-old boys and girls. Increased BF%, AF%, WC and BMI were all correlated with poorer FMS results. The inverse association between FMS and body composition measured with DXA (BF% and AF%) is an important finding, as body fatness and specifically abdominal fatness are associated with less favourable cardiovascular risk factor status in children. Lower FMS level may obstruct a child's participation in physical activities and, as a consequence, lead to greater risk for weight gain and future health risks. The findings of this study are important for kindergarten and primary school teachers, parents and health care personnel working with overweight and obese children and when planning obesity intervention programs.

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Notes on contributors

Sari Slotte is a PhD student and a researcher in Sport and Health Sciences at the University of Jyväskylä, Finland and her research interests are on childhood obesity, fundamental movement skills and health related fitness. She is also a physical education and health sciences lecturer at the University of Helsinki

Arja Sääkslahti holds a Doctoral degree in Sport Sciences. She is a senior departmental researcher at the University of Jyväskylä, Department of Sport Sciences. Most of her publications deal with preschool aged children's physical activities, fundamental motor skill development, and children's health. She has also published physical education curriculums for preschool and primary school.

Jari Metsämuuronen (PhD, Adjunct Professor) is one of the leading methodological experts in Finland. He has popularized research methodology in 13 volumes of the Methodology series. The Handbook of Practical Qualitative Research (in Finnish) was published in 2006. His largest book, Basics of Research Methods in Human Sciences, will be published in English by SAGE Publication Inc. in 2015. He has served as an international consultant in Sri Lanka, Kenya, Ethiopia, Palestine and Nepal. From 1998 onwards he has been a senior methodologist in the student assessment unit on the Finnish National Board of Education.

Pauli Rintala is Professor of Adapted Physical Activity at the University of Jyväskylä, Department of Sport Sciences. His research interests are on individuals with special needs, their motor skills and fitness issues and physical activity. He has published over 50 peer-reviewed articles and edited and written several textbooks in Adapted Physical Activity.

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Table 1. Descriptive characteristics of the participants

Variable	All (n=304) Mean (SD)	Boys (n=153) Mean (SD)	Girls (n=151) Mean (SD)	*P*	Cohen's d
Age	8.6 (0.2)	8.6 (0.2)	8.6 (0.2)	0.634	0.05
BMI	17.1 (2.1)	17.1 (2.2)	17.1 (2.1)	0.971	0.00
AF (%)	23.3 (11.2)	20.2 (10.9)	26.5 (10.5)	<0.001	-0.59
BF (%)	21.6 (7.7)	19.2 (7.7)	24.0 (6.9)	<0.001	-0.66
WC (cm)	59.7 (6.2)	60.1 (6.2)	59.3 (6.1)	0.286	0.12
OC (range 0-16)	11.4 (3.8)	13.3 (3.3)	9.4 (3.3)	<0.001	1.19
LM (range 0-24)	15.8 (3.3)	15.2 (3.2)	16.4 (3.3)	0.002	-0.36
Total FMS (range 0-32)	21.9 (4.8)	23.5 (4.5)	20.3 (4.5)	<0.001	0.70

Abbreviations: AF: abdominal fat, BF: total body fat, BMI: body mass index, LM: locomotor skills raw score, OC: object control skills raw score, Total FMS: total fundamental movement skills score, WC: waist circumference

Table 2. Descriptive characteristics of the participants divided into BMI groups

Variables	Healthy weight (n=246) Mean (SD)	Overweight/Obese (n=58) Mean (SD)	*P*	Cohen's d
Age	8.6 (0.2)	8.6 (0.2)	0.26	-0.17
BMI	16.3 (1.2)	20.4 (2.0)	<0.001	-2.90
AF (%)	19.9 (8.8)	37.7 (8.7)	<0.001	-2.04
BF (%)	19.3 (6.2)	31.4 (5.4)	<0.001	-2.02
WC (cm)	57.6 (3.9)	68.3 (6.4)	<0.001	-2.39
OC	11.7 (3.7)	9.9 (3.9)	0.001	0.49
LM	16.3 (3.1)	13.4 (3.2)	<0.001	0.95
Total FMS	22.6 (4.5)	18.8 (4.8)	<0.001	0.84

Abbreviations: AF: abdominal fat, BF: total body fat, BMI: body mass index, LM: locomotor skills raw score (range 0-24), OC: object control skills raw score (range 0-16), Total FMS: total fundamental movement skills score (range 0-32), WC: waist circumference

Table 3. Descriptive characteristics of boys and girls divided into low, moderate and high FMS groups

	Variables	Low (n=28) Mean (SD)	Moderate(n=53) Mean (SD)	High (n=72) Mean (SD)	*P*	η^2	Cohen's d	Tukey
Boys	Age	8.7 (0.2)	8.6 (0.2)	8.6 (0.2)	0.187	0.022	0.37	ns
	BMI	18.2 (2.4)	17.2 (2.4)	16.6 (1.7)	0.003	0.073	0.69	13
	Height (cm)	135.1 (5.8)	135.9 (6.3)	133.6 (5.7)	0.112	0.029	0.42	ns
	Weight (kg)	33.3 (5.9)	31.9 (6.1)	29.7 (4.7)	0.007	0.065	0.65	13
	WC (cm)	63.2 (7.1)	60.4 (6.5)	58.6 (5.2)	0.003	0.074	0.69	13
	BF (%)	25.1 (8.4)	19.8 (7.7)	16.5 (5.9)	<0.001	0.17	1.11	12 13 23
	AF (%)	28.1 (11.9)	20.6 (11.5)	16.8 (8.3)	<0.001	0.141	0.99	12 13 23
	FFM (g)	23340.5 (2240.8)	23927.7 (3025.3)	2341.1 (2752.7)	0.52	0.009	0.23	ns
	OC (range 0-16)	8 (3.4)	13.3 (1.8)	15.4 (0.8)	<0.001			12 13 23
	LM (range 0-24)	11.7 (3.1)	14.1 (2.2)	17.3 (2.1)	<0.001			12 13 23
	Total FMS (range 0-32)	15.8 (3.6)	22.7 (1.2)	27.0 (1.6)	<0.001			12 13 23

	Variables	Low (n=73) Mean (SD)	Moderate(n=49) Mean (SD)	High (n=29) Mean (SD)	*P*	η^2	Cohen's d	Tukey
Girls	Age	8.6 (0.2)	8.6 (0.2)	8.6 (0.2)	0.513	0.009	0.23	ns
	BMI	17.6 (2.6)	16.8 (1.6)	16.3 (1.1)	0.014	0.056	0.60	13
	Height (cm)	134.1 (6.4)	134.3 (4.5)	132.0 (5.3)	0.186	0.023	0.38	ns
	Weight (kg)	31.8 (6.7)	30.4 (4.1)	28.5 (3.5)	0.024	0.049	0.56	13
	WC (cm)	60.6 (7.3)	58.9 (4.6)	56.6 (3.5)	0.01	0.061	0.62	13
	BF (%)	25.4 (7.7)	23.5 (6.0)	21.3 (5.2)	0.018	0.053	0.58	13
	AF (%)	28.9 (11.4)	25.9 (9.8)	21.8 (7.6)	0.007	0.064	0.64	13
	FFM (g)	22123.9 (2940.1)	21880.0 (2044.0)	21081.3 (2090.4)	0.173	0.023	0.38	ns
	OC (range 0-16)	7.0 (2.6)	10.7 (1.6)	13.4 (1.7)	<0.001			12 13 23
	LM (range 0-24)	14.5 (2.7)	17.1 (2.2)	19.9 (2.7)	<0.001			12 13 23
	Total FMS (range 0-32)	16.6 (2.7)	22.1 (1.1)	26.7 (2.1)	<0.001			12 13 23

Abbreviations: AF: abdominal fat, BF: total body fat, BMI: body mass index, FFM: fat free mass, LM: locomotor skills raw score, OC: object-control skills raw score, 1: Low, 2: Moderate, 3: High, Total FMS: total fundamental skills score, WC: waist circumference,

Table 4. Spearman's correlations between FMS and different obesity variables in boys and girls

Boys

Variables	OC	*P*	LM	*P*	Total FMS	*P*
BMI	-.194	0.017	-.316	<0.001	-.287	<0.001
WC	-.200	0.013	-.343	<0.001	-.308	<0.001
BF %	-.304	<0.001	-.383	<0.001	-.408	<0.001
AF %	-.262	0.001	-.352	<0.001	-.362	<0.001

Girls

Variables	OC	P	LM	P	Total FMS	P
BMI	-.157	0.054	-.292	<0.001	-.259	<0.001
WC	-.158	0.054	-.332	<0.001	-.276	<0.001
BF %	-.173	0.034	-.318	<0.001	-.276	<0.001
AF %	-.176	0.031	-.312	<0.001	-.276	<0.001

Abbreviations: AF: abdominal fat, BF: total body fat, BMI: body mass index, LM: locomotor skills score, OC: object control skills score, Total FMS: total fundamental movement skills score, WC: waist circumference,

III

EIGHT-YEAR-OLD CHILDREN WITH HIGH CARDIORESPIRATORY FITNESS HAVE LOWER OVERALL AND ABDOMINAL FATNESS

by

Stigman S (Slotte S), Rintala P, Kukkonen-Harjula K, Kujala U,
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IV

ASSOCIATIONS OF MUSCULAR FITNESS AND BODY COMPOSITION IN CHILDREN

by

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Associations of muscular fitness and body composition in children

Sari Slotte[a,b,c], Katriina Kukkonen-Harjula[d], Marjo Rinne[b], Juha Valtonen[c] and Pauli Rintala[a]

[a]Faculty of Sport and Health Sciences, University of Jyväskylä, Finland; [b]The UKK Institute for Health Promotion Research, Tampere, Finland; [c]Faculty of Educational Sciences, University of Helsinki, Finland; [d]Faculty of Medicine and Health Technology, Tampere University, Tampere, Finland

ABSTRACT

Purpose: To examine the associations between muscular fitness (MF) and body composition.

Method: MF was assessed with three tests of FitnessGram test battery. Total body fat percentage (BF%), abdominal fat percentage (AF%) and fat-free mass (FFM) were measured by dual-energy X-ray absorptiometry (DXA). The IOTF body mass index (BMI) cut-offs were used to define healthy weight, overweight, and obesity.

Results: MF was inversely associated with BF% and AF%. The children in the moderate and high MF groups had significantly lower BF% and AF% compared with the children in the low MF group within the same BMI category. After adjusting for cardiorespiratory fitness (CRF), BMI and sex, the differences between the MF groups were significant for BF% but not for AF%.

Conclusion: There were significant inverse associations between MF and DXA -measured adiposity. Within the same BMI category, total and abdominal adiposity were lower in children with moderate or high MF than in children with low MF.

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Adiposity; DXA; health-related fitness; obesity; overweight

Introduction

Over the recent decades, obesity has increased among children and adolescents in most countries worldwide (Di Cesare et al., 2019; NCD, 2017; Ng et al., 2014). Furthermore, declines in physical activity (PA) and physical fitness have also been observed (Aubert et al., 2018; Führer, Kliegl, Arntz, Kriemler, & Granacher, 2021; Tomkinson & Olds, 2007; Tremblay et al., 2010). This is a very worrying trend because both physical fitness and obesity are strongly related to health status in children and adolescents (Di Cesare et al., 2019; Ortega et al., 2018; Ortega, Ruiz, Castillo, & Sjöström, 2008). In addition, childhood obesity tends to track into adulthood, corresponding to an increased risk of cardiometabolic diseases and mortality later in life (Di Cesare et al., 2019; Reilly & Kelly, 2011; Singh, Mulder, Twisk, van Mechelen, & Chinapaw, 2008).

The treatment of obesity is relatively challenging, and thus the potential of physical fitness to attenuate the negative consequences of obesity has been of interest to researchers (Ortega et al., 2018). Certain components of physical fitness, such as cardiorespiratory fitness (CRF) and muscular fitness (MF), are considered to comprise health-related fitness (American College of Sports Medicine, 2018; Caspersen, Powell, & Christenson, 1985), and among these health-related fitness components,

CONTACT Sari Slotte sari.a.slotte@jyu.fi
The study was performed at the UKK Institute for Health Promotion Research, Tampere, Finland

CRF has been studied the most. Prior studies have clearly shown that CRF is an indicator of health and is strongly associated with health outcomes, such as obesity and abdominal obesity in youth (Ortega et al., 2018; Raghuveer et al., 2020). In addition, there is evidence that increasing CRF in childhood, regardless of weight status, could reduce the risk of developing cardiometabolic health problems associated with obesity later in life (Schmidt, Magnussen, Rees, Dwyer, & Venn, 2016).

Less is still known about the associations between MF and obesity in childhood and in addition, most of the data available from previous studies, are based on body mass index (BMI) -defined obesity (Smith et al., 2014; Thivel, Ring-Dimitrioum, Weghuber, Frelut, & O'Malley, 2016). However, BMI is a proxy measure because it does not distinguish between fat mass and non-fat mass (Marra, Sammarco, & De Lorenzo, 2019), whereas dual-energy X-ray absorptiometry (DXA) is the current reference method for the assessment of body composition, providing accurate estimates of total body fat (BF), abdominal region fat (AF) and fat-free mass (FFM) (Marra et al., 2019). As direct measures of body composition are better indicators of adiposity and health risk (Zeng, Dong, Sun, Xie, & Cui, 2012) and also MF is increasingly thought to be important marker of health, understanding the associations between accurately measured adiposity and MF may contribute to the development of evidence-based interventions to prevent childhood obesity.

The aim of this population-based cross-sectional study of eight-year-old children was to examine the associations between MF and body composition assessed by DXA.

Methods

Participants

A random sample ($n = 750$) of eight-year-old children, born in the same year and living in Tampere, Finland, was drawn from the population register. The families of the children were mailed an invitation to participate in the study and informed of the purpose and nature of the study and its measurements. The families willing to participate in the study, responded to the invitation and booked a suitable research time for them. The voluntary children, accompanied by one of their parents, arrived at the UKK-institute research site and both gave their written informed consent upon arrival. The final sample of voluntary children, who provided complete data regarding their MF, CRF, body composition, and anthropometric measurements, consisted of 304, approximately eight years old children (151 girls and 153 boys; mean 8.6 years; range 8.2–9.2 years) The study was approved by the Ethics Committee of Pirkanmaa hospital district (the reference number: R05105).

Muscular fitness (MF) assessments

The assessment of MF was accomplished with three test items from the FitnessGram health-related fitness test battery for children and adolescents, in accordance with the instructions outlined in the test manual (Meredith & Welk, 2010). The chosen test items included a curl-up test, a trunk lift test, and a modified pull-up test. The curl-up test was used to assess abdominal muscle strength and endurance. This test required each participant to perform as many curl-ups as possible following a given cadence. One trial was allowed and the resulting score was the number of curl-ups correctly performed. The trunk lift test was used to assess the strength of the back extensor muscles. This test required each participant to lie prone, lift their upper body off the floor using the extensor muscles of the back, and hold that position while the distance from floor to the child's chin was measured. The resulting score was the distance measured in centimetres. Two trials were allowed and the highest score was recorded. The modified pull-up test was used to assess upper body strength and endurance. This test required each participant to lie in a supine position with their body horizontally straight, grasp a bar placed just out of reach, and pull up toward the bar. One trial was allowed and the resulting score was the number of successfully completed modified pull-ups performed.

The children arrived for MF tests in pairs and before the actual test, the children were given time to practice in pairs but performed the actual test one at a time. Attention was given by the researcher to performance technique during all the tests. Each child was assessed individually by the same experienced researcher (SS). The standardized total MF score was computed from the three test item scores. The three MF test item scores were standardized separately for both sexes, after which the different MF -variables were combined into one variable, and finally divided into the thirds of the obtained variable: low MF (the lowest third), moderate MF (the middle third) or high MF (the highest third).

Cardiorespiratory fitness (CRF) assessment

The assessment of CRF was accomplished with the 20-m shuttle run test (20-mSRT), which involves continuously running between two lines placed 20 m apart, keeping time with a recorded sound signal at a specific pace that grows faster with each minute (Leger, Mercier, Gadoury, & Lambert, 1988; Nevill et al., 2021). We have described the test procedure in detail previously (Stigman et al., 2009). The result of this test was a CRF score, expressed as the number of 20-m-distance laps completed by each participant.

Body composition and anthropometric measurements

The total body fat percentage (BF%), abdominal region fat percentage (AF%), and fat-free mass (FFM) of each participant were measured with DXA (GE Lunar Prodigy Advance, GE Lunar Radiation Corp., Madison, WI). Abdominal region fat, which includes intra-abdominal fat and subcutaneous fat, was evaluated at a manually delineated region of interest that included the soft tissue area of the body between the lowest ribs and the superior border of the iliac crest. Waist circumference (WC) was measured with a measuring tape, midway between the lowest rib and the superior border of the iliac crest. Height was measured to the nearest 0.1 cm and weight was determined using a high-precision electronic scale (F 150S-D2, Sartorius AG, Goettingen, Germany) to the nearest 0.1 kg, and the measurements were used to calculate BMI (kg/m2). The participants were classified as healthy weight, overweight or obese, according to the BMI cut-offs of the International Obesity Task Force (IOTF) for age and sex (Rolland-Cachera, 2011), as recommended by the European Childhood Obesity Group (Jin et al., 2020).

Statistical analysis

Means and standard deviations were calculated for all variables. Pearson's correlation coefficient was used to assess the correlations between the variables. A one-way analysis of variance (ANOVA) was used to examine differences in participant characteristics across the MF groups. When an ANOVA result was statistically significant ($p < 0.05$), a Tukey's or Tamhane's post hoc comparison tests was used to identify specific between-group differences. The influence of MF on BF% and AF% was determined using an analysis of covariance (ANCOVA). The dependent variables (BF% and AF%) were included in the models in their original continuous scales of measurement, and MF group (low, moderate or high) was entered as a factor variable. All models included BMI, sex, and CRF as covariates, and all models were run separately for BF% and AF%. All statistical analyses were carried out using SPSS version 26.0 (IBM Corp, Armonk, NY, USA), and the level of significance was set at $p = .05$.

Results

According to the BMI cut-offs of the IOTF, 80.9% of the participants were of healthy weight (girls: 81.4%, boys: 80.4%), 17.1% were overweight (girls: 17.9%, boys: 16.3%) and 2,0% were obese (girls: 0.7%, boys: 3.3%).

The participant characteristics are shown in Table 1. DXA-measured body composition differed significantly by sex; specifically, girls had significantly higher BF% and AF% than boys, and boys had significantly higher FFM than girls. There were also statistically significant between-sex differences in the MF test results, in that girls were more proficient than boys in the curl-up and trunk lift tests.

The Pearson's correlations coefficients between body composition (BF%, AF%, and FFM) and MF test item results and total MF scores, are shown in Table 2. When the MF test items were examined separately, the strongest correlations were found (among both sexes) between modified pull-up performance and BF% and between modified pull-up performance and AF%. Furthermore, BF% and AF % were significantly correlated with total MF scores (among both sexes). Statistically significant correlation was found between FFM and modified pull-up performance among boys.

Table 3 shows the body composition characteristics in the low, moderate, and high MF groups by sex. Statistically significant differences in weight, BMI, and WC were found between MF groups among both sexes. Furthermore, BF% and AF% were significantly higher among both sexes in the low MF group compared with the moderate and high MF groups.

The participants' body composition characteristics were examined within the BMI categories (healthy weight, overweight and obese) and compared between the low, moderate, and high MF groups (Table 4). Among the healthy weight children, BF% was significantly higher in the low MF group than in the moderate and high MF groups, and AF% was significantly higher in the low MF group than in the high MF group. Among the overweight and obese children, BF% was significantly higher in the low MF group than in the moderate and high MF groups, and the AF% was significantly higher in the low MF group than in the moderate MF group. Furthermore, weight and BMI differed between the low and moderate MF groups among the overweight and obese children.

When the associations between MF and BF% and AF% were examined, adjusting for CRF, BMI, and sex, the differences between MF groups were statistically significant for BF% ($p = 0.005$) but not for AF% ($p = 0.192$). Specifically, the statistically significant differences in BF% were found between the high and low MF groups ($p = 0.011$) and between the moderate and low MF groups ($p = 0.010$). (Figure 1a and b).

Discussion

The aim of the present study was to examine the associations between MF and accurately assessed body composition in a population-based sample of eight-year-old children. The main finding was that there were strong inverse associations between MF and total body fatness and between MF and abdominal fatness. The children with lower MF had higher total body adiposity and abdominal

Table 1. Characteristics of all the participants by sex. Means (SD).

	All ($N = 304$)	Girls ($n = 151$)	Boys ($n = 153$)	p
Weight (kg)	30.9 (5.6)	30.7 (5.5)	31.2 (5.6)	.482
Height (cm)	134.2 (5.8)	133.8 (5.6)	134.7 (6.0)	.174
BMI (kg/m^2)	17.1 (2.1)	17.1 (2.1)	17.1 (2.2)	.971
Waist circumference (cm)	59.7 (6.2)	59.3 (6.1)	60.1 (6.2)	.286
Total body fat (%)	21.6 (7.7)	24.0 (6.9)	19.2 (7.7)	<.001
Abdominal region fat (%)	23.3 (11.2)	26.5 (10.5)	20.2 (10.9)	<.001
Fat-free mass (kg)	22.7 (2.8)	21.8 (2.5)	23.6 (2.8)	<.001
Muscular fitness tests				
Curl up (reps)	11.0 (11.8)	12.9 (12.4)	9.2 (10.9)	.006
Trunk lift (cm)	14.1 (3.8)	15.5 (3.8)	12.8 (3.4)	<.001
Modified pull-up (reps)	5.5 (4.4)	5.2 (4.0)	5.8 (4.8)	.250
Cardiorespiratory test				
20-m shuttle run test (laps)	22.5 (8.5)	20.6 (7.2)	24.2 (9.5)	<.001

Table 2. The Pearson's correlation coefficient between body composition and MF test items and MF total score by sex.

		Curl-up	p	Trunk lift	p	Pull-up	p	Total MF	p
Girls	Total body fat (%)	**−.194**	.017	−.079	ns	**−.550**	<.001	**−.385**	<.001
	Abdominal fat (%)	**−.200**	.014	−.032	ns	**−.524**	<.001	**−.353**	<.001
	Fat-free mass (kg)	−.013	ns	−.102	ns	−.147	ns	−.027	ns
Boys	Total body fat (%)	**−.191**	.018	.025	ns	**−.496**	<.001	**−.316**	<.001
	Abdominal fat (%)	**−.196**	.015	.047	ns	**−.477**	<.001	**−.299**	<.001
	Fat-free mass (kg)	−.091	ns	.102	ns	**−.189**	.020	−.085	ns

Statistically significant differences are bolded, ns; not significant.

Table 3. Body composition of the girls and boys by thirds of muscular fitness (low, moderate and high MF). Means (SD).

	Girls			Boys		
	Low MF[a] (*n* = 50)	Mod MF[b] (*n* = 50)	High MF[c] (*n* = 51)	Low MF[a] (*n* = 50)	Mod MF[b] (*n* = 52)	High MF[c] (*n* = 51)
Weight (kg)	32.7 (7.2) [c]	30.0 (4.5)	30.0 (4.0) [a]	33.1 (6.5) [b]	30.1 (4.2) [a]	30.4 (5.5)
Height (cm)	134.9 (6.1)	133.0 (5.6)	133.4 (5.1)	136.3 (6.5)	134.2 (5.8)	133.5 (5.5)
BMI (kg/m^2)	17.8 (2.8)[c]	16.9 (1.7)	16.5 (1.5)[a]	17.8 (2.6)[b]	16.6 (1.5)[a]	16.9 (2.2)
WC (cm)	62.0 (7.8)[b,c]	58.0 (4.5)[a]	58.0 (4.6)[a]	62.1 (7.2)[b]	58.9 (4.8)[a]	59.3 (6.1)
BF (%)	27.8 (7.5)[b,c]	23.0 (5.8)[a]	21.3 (6.9)[a]	22.9 (8.8)[b,c]	17.2 (5.6)[a]	17.5 (7.1)[a]
AF (%)	31.6 (11.1)[b,c]	25.5 (9.4)[a]	22.6 (9.0)[a]	24.8 (12.8)[b,c]	17.7 (7.6)[a]	18.2 (10.7)[a]
FFM (kg)	21.9 (3.1)	21.7 (2.2)	21.9 (2.5)	23.8 (2.9)	23.5 (2.7)	23.5 (2.8)

AF; abdominal region fat, BF; total body fat, FFM; fat-free mass, WC; waist circumference.
Superscripts refer to the MF category from which the relevant variable is significantly different (*p*<.05) according to Tukey or Tamhane post hoc -test.

Table 4. The body composition characteristics within the BMI categories (healthy weight, overweight and obese) by the MF groups. Means (SD).

	Healthy weight			Overweight and obese		
	Low MF[a] (*n* = 69)	Mod MF[b] (*n* = 86)	High MF[c] (*n* = 91)	Low MF[a] (*n* = 31)	Mod MF[b] (*n* = 16)	High MF[c] (*n* = 11)
Weight (kg)	29.8 (4.4)	29.0 (3.7)	28.9 (3.4)	39.7 (6.2)[b]	35.6 (3.1)[a]	38.8 (6.0)
Height (cm)	134.5 (6.3)	133.3 (5.8)	133.1 (5.2)	138.1 (5.7)	135.4 (4.9)	137.0 (4.9)
BMI (kg/m^2)	16.4 (1.4)	16.3 (1.2)	16.3 (1.1)	20.9 (2.3)[b]	19.4 (0.8)[a]	20.5 (2.2)
WC (cm)	58.4 (4.2)	57.1 (3.6)	57.6 (4.0)	70.0 (6.9)	65.6 (3.1)	67.6 (7.6)
BF (%)	21.4 (6.8)[b,c]	18.8 (5.8) [a]	18.1 (5.7) [a]	34.1 (4.1)[b,c]	27.0 (4.9)[a]	30.2 (4.7)[a]
AF (%)	22.3 (9.4)[c]	19.6 (8.3)	18.5 (8.3) [a]	41.3 (7.0)[b]	31.9 (7.9)[a]	36.2 (9.8)
FFM (kg)	22.0 (2.9)	22.2 (2.5)	22.3 (2.3)	24.8 (2.9)	24.7 (2.3)	25.7 (3.2)

AF; abdominal region fat, BF; total body fat, FFM; fat-free mass, WC; waist circumference.
Superscripts refer to the MF category from which the relevant variable is significantly different (*p*<.05) according to Tukey or Tamhane post hoc -test.

adiposity compared to the children with higher MF. These associations were observed among both sexes. The present results are consistent with and expand upon previous findings of associations between MF and obesity as a health outcome, for which obesity has mainly been defined based on BMI or abdominal obesity indicated by WC (Ortega et al., 2008; Smith et al., 2014; Thivel et al., 2016). However, making comparisons between the studies of these associations is challenging because there are no standard procedures for the assessment of MF in children. Assessments of MF with lower body weight bearing tests have consistently been shown to be inversely associated with adiposity, which is commonly measured by BMI or WC (Ortega et al., 2008; Smith et al., 2014; Thivel et al., 2016). Contrary to these findings, positive associations have been found between muscle strength and adiposity, when muscle strength has been assessed with the handgrip test (Ortega et al., 2008; Smith et al., 2014; Thivel et al., 2016).

Adiposity and especially increased abdominal adiposity (measured by DXA) have been shown to be independently associated with increased cardiometabolic health risk in obese children and

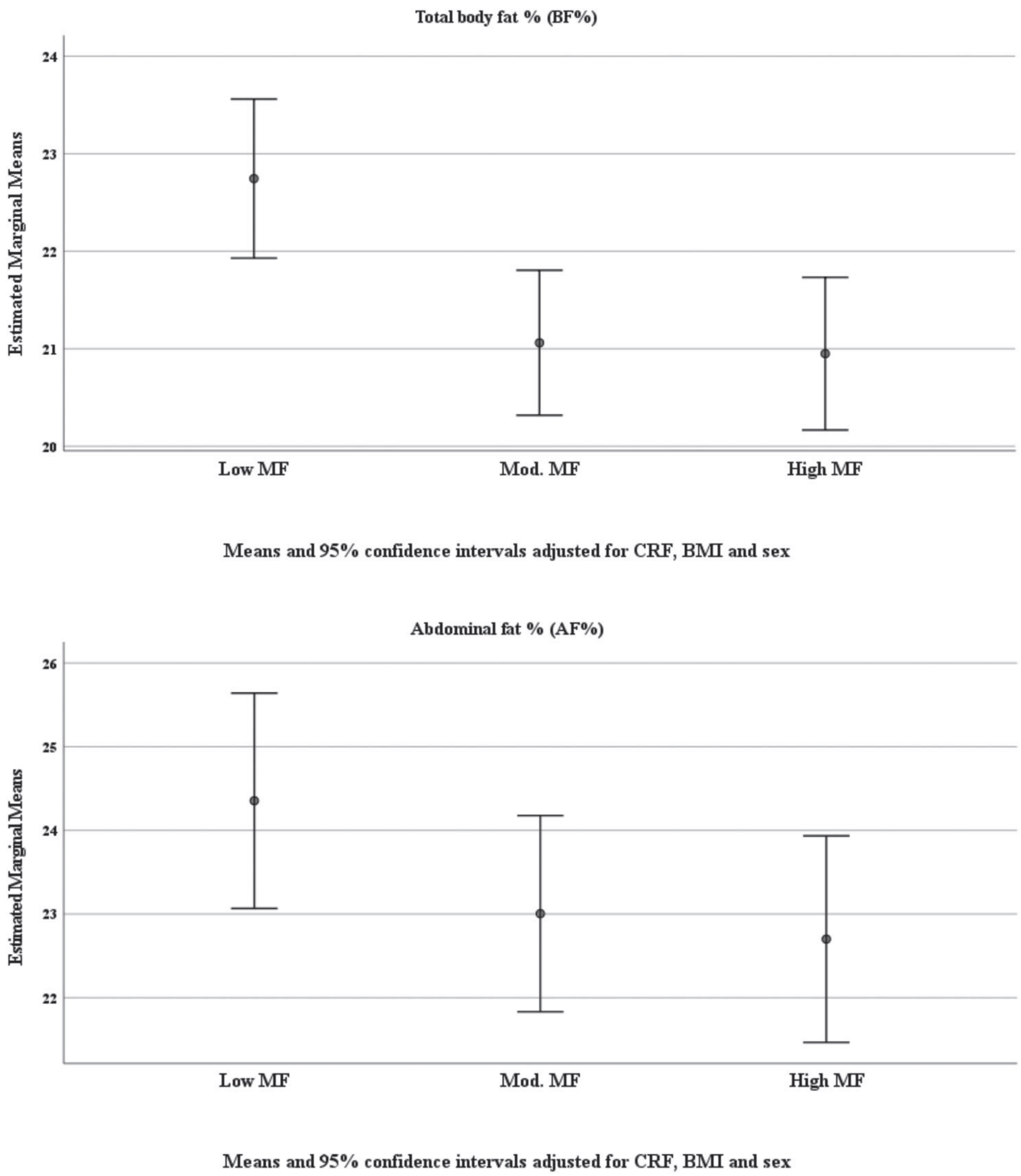

Figure 1. Mean cardiorespiratory fitness (CRF), body mass index (BMI), and sex adjusted values for low, moderate and high muscular fitness (MF) groups, for total body fat percentage (BF %) and abdominal region fat percentage (AF %).

adolescents (Jin et al., 2020). Conversely, there is accumulating evidence that health-related fitness, especially CRF, is associated with adiposity and may counteract the negative consequences of obesity in childhood (Ortega et al., 2018; Schmidt et al., 2016). Less is still known about the effect of MF in children and adolescents (Ortega et al., 2018). In longitudinal studies (García-Hermoso, Ramírez-Campillo, & Izquierdo, 2019) MF has been found to be inversely associated with adiposity and cardiometabolic risk. However, none of these studies assessed body composition with sophisticated methods. It is not possible to estimate whether MF attenuates the obesity-related future health risks of the children in the present cross-sectional research. However, the overweight and obese children with higher MF had significantly lower total and abdominal adiposity than the children with lower MF at the same BMI category. The similar association was observed among the healthy-weight children. Regardless of BMI category, higher MF was associated with lower total and abdominal adiposity.

The present study examined the associations between MF and DXA -measured adiposity after adjusting for CRF, BMI and sex, it was found that children with higher MF had lower total adiposity compared to children with lower MF, but no statistically significant differences were found in abdominal adiposity between MF groups. Further studies of children, using sophisticated methods of body composition measurement are needed to determine whether higher MF contributes to lower total and abdominal adiposity or whether higher MF counteracts the negative health consequences of obesity.

The main strength of this study was the use of an accurate method (DXA) to assess body composition. Another strength was that all the participating children were born in the same year and recruited from the sample, which was randomly drawn from a population register. The sample of participating children was representative of their age group, considering the distribution of healthy-weight, overweight, and obese children (Vuorela, 2011). This study also had limitations. One limitation was that causal inferences could not be made due to the cross-sectional design of the study. In addition, the use of field tests to determine MF may not be ideal. Excessive body fat is an extra load that may adversely affect MF performance, especially when MF performance is measured with weight-bearing tests. However, field tests seem to provide results comparable to laboratory-based data in the assessment of overall MF in children, including those with obesity (Thivel et al., 2016). In the present study, MF was assessed with three test items of the FitnessGram, which is a valid and reliable, practical field test battery that has been widely used test to assess health-related fitness in children and youth (Kolimechkov, 2017; Plowman, 2013). These three test items mainly assess middle and upper body strength and endurance; thus, these items may be more suitable for children with excessive weight compared to test items that measure weight-bearing lower body strength.

The prevention of childhood obesity and the improvement of health-related fitness both have great impacts on public health (Chaput et al., 2020). Thus, the results of the present study of significant inverse associations between MF and DXA-measured total and abdominal adiposity in eight-year-old children, are important. Longitudinal studies have shown that childhood obesity often tracks into adulthood, and obesity is often difficult to treat (Di Cesare et al., 2019). In addition, studies have shown that youth with low MF are at an increased risk of maintaining low MF level into adulthood (Fraser et al., 2017). The persistence of weight status, the known health risks of obesity, and the low efficacy of obesity management, highlight the importance of health-related fitness. In particular, it would be important to inform kindergarten and lower grade school teachers about the importance of MF for health and for regularly include age-appropriate motivational MF enhancing activities.

Conclusion

The results of this population-based cross-sectional study revealed significant inverse associations between MF and DXA-measured total and abdominal adiposity in eight-year-old children. Within the same BMI category, total and abdominal adiposity were lower in children with moderate or high MF than in children with low MF. After adjusting for CRF, children with moderate or high MF had lower total adiposity compared to children with low MF. More studies utilizing accurate measures of body composition are needed to determine whether higher MF could attenuate the negative health consequences of obesity in children.

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No potential conflict of interest was reported by the author(s).

Notes on contributors

Sari Slotte, M.S.c (Sport and Health Sciences) is PhD student at Faculty of Sport and Health Sciences, University of Jyväskylä and university teacher in didactics of physical education at Faculty of Educational Sciences, University of Helsinki. Her research interests are on childhood obesity, fundamental movement skills and health related fitness.

Katriina Kukkonen-Harjula, MD, Ph.D., is an associate professor in exercise and sports medicine in Faculty of Medicine and Health Technology in Tampere University, Finland. Her research interests are health-related physical activity, evidence-based clinical guidelines, and rehabilitation of elderly population. She has published over 70 international peer-reviewed publications.

Marjo Rinne is an emerita senior researcher at UKK Institute – Centre for Health Promotion Research. Her research interests have been on promoting health-enhancing physical activities. She has presented in 10 international conferences, published over 20 international peer-reviewed publications, and co-authored four textbooks in the field of physical activity which enhances health and prevents diseases, and Health-Related Fitness Testing.

Juha Valtonen, PhD (education) and MA (physical education) is a senior university lecturer in the didactics of physical education at the University of Helsinki, Finland. His research interests are on teacher development and children's physical activity. He has presented in eight conferences and published 13 peer-reviewed publications. He has worked as a university lecturer in teacher education almost for four decades.

Pauli Rintala is a professor in Adapted Physical Activity at the University of Jyväskylä. His research interests are on individuals with special needs, their motor skills and fitness issues and physical activity. He has presented in more than 50 international conferences, published over 80 international peer-reviewed publications, and co-authored five textbooks in the field of Adapted Physical Activity.

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