ANNA PULAKKA

Physical Activity of Malawian Toddlers

Measurement, effect of nutrient supplements and parental perceptions

ACADEMIC DISSERTATION
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University of Tampere, School of Medicine
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Supervised by
Professor Per Ashorn
University of Tampere
Finland
PhD Ulla Ashorn
University of Tampere
Finland

Reviewed by
Professor Mikael Fogelholm
University of Helsinki
Finland
Docent Arja Sääkslahti
University of Jyväskylä
Finland

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Abstract

The effect of complementary feeding interventions targeting improved nutritional status of children in food insecure settings has typically been measured by indicators related to growth, morbidity, micronutrient intake and cognitive development. Physical activity is an additional indicator of children's health and a determinant of child development. Physical activity can currently be objectively measured with accelerometers, but the devices need value calibration and validation in the target group before they can be used. Parental encouragement for physical activity is associated with higher level of toddlers' and preschool aged children's physical activity. Because attitudes of parents' can influence young children's physical activity, understanding their perceptions of physical activity would be important.

This PhD project is based on three studies. The aim was to assess the feasibility and validity of an accelerometer in measuring physical activity of 18 month-old children in Malawi, to measure effect of an intervention with lipid-based nutrient supplement on Malawian toddlers' physical activity and to investigate perceptions of young children's parents toward physical activity and child development.

In study I, 56 Malawian children aged 16.0 to 18.5 months wore a tri-axial ActiGraph GT3X accelerometer for one week. Research assistants visited them daily to check on the device use and twice a week to video record the children in free-play sessions. We compared the accelerometer readings to the video observations coded by the Children's Physical Activity Form method and carried out a wear-time analysis excluding the first and the last measurement day, night time and minimum of 20 minutes strings of zero counts. In study II, 1932 Malawian children were randomized into five groups receiving 10 to 40 g doses of lipid-based nutrient supplement (LNS) daily from the age of 6 to 18 months and a control group. Their activity was measured with ActiGraph GT3X+ accelerometer at the end of the intervention. In study III, we conducted in-depth interviews with 16 parents, a focus group discussion with six parents and two key informant interviews in Malawi.

Of the 52 participants included to wear-time analysis in study I, 79% (95% CI 65 to 89%) had the minimum required wear-time, i.e. four days with 10 hours of

accelerometer data. In study II the corresponding figure was 60% (95% CI 58% to 63%) for the 1339 participants that wore the accelerometer. Majority of the guardians (70% in study I and 96% in study II) stated that the measurement went well.

Accelerometer counts increased in study I as the observed activity intensity increased, with the difference between light and moderate activity being statistically significant in all the measured axes and vector magnitude. Count cut points of 208 counts/15 seconds for vector magnitude and 35 counts/15 seconds for the vertical axis indicated the best accuracy, i.e. equal specificity and sensitivity, in separating sedentary-to-light activity from moderate-to-vigorous activity in receiver operating characteristic curve analysis. The vector magnitude cut point demonstrated 94.2% sensitivity and 90.9% specificity, and the vertical axis cut point 84.1% sensitivity and 84.6% specificity for capturing moderate-to-vigorous physical activity when applied to the second video recordings from the same children.

Children in the control group of study II had slightly lower mean accelerometer counts and less time in moderate-to-vigorous physical activity than children in the five intervention groups, but the differences were not statistically significant. Results remained essentially similar when activity was adjusted for the participants' length-for-age z-scores and weight-for-length z-scores at six months, sex, season of birth, maternal education, maternal age, and household food insecurity access scale scores.

Both the parents and the key informants in study III perceived physical activity as a positive attribute of children. The parents described active children as ones who acquire practical and cognitive skills early, are socially competent, stay healthy and move around much. Being physically active was well in line with the developmental goals parents had for their children. Parents viewed balanced diet, good health and stimulation from other people and in the form of play equipment as facilitators for physical activity.

In conclusion, the ActiGraph accelerometer is a valid and feasible method for assessing toddlers' physical activity. Our results do not support the hypothesis that LNS in 10 to 40 g quantities per day would increase physical activity among toddlers in semi-rural Malawi. Parental perceptions of physical activity in this area comprise both mental and physical qualities of children.

Tiivistelmä

Lisäravitsemusinterventioiden vaikutuksia on tyypillisesti mitattu kasvuun, sairastavuuteen, ravitsemustilaan ja kehitykseen liittyvillä indikaattoreilla. Yksi lisä lasten terveyteen liittyviin indikaattoreihin on fyysinen aktiivisuus, joka on myös lasten kehitykseen liittyvä taustatekijä. Fyysistä aktiivisuutta voidaan nykyään mitata kiihtyvyysantureilla, mutta nämä laitteet pitää kalibroida ja validoida kussakin kohderyhmässä ennen käyttöä. Vanhempien rohkaiseva asenne aktiivisuutta kohtaan on yhteydessä taapero- ja leikki-ikäisten lasten fyysisen aktiivisuuden määrään, ja siksi olisi tärkeää ymmärtää millaisen merkityksen he antavat aktiivisuudelle.

Tämä väitöskirjatyö perustuu kolmeen osatutkimukseen. Tavoitteena oli arvioida kiihtyvyysmittarin käyttökelpoisuutta ja validiteettia 18 kuukauden ikäisten malawilaisten lasten aktiivisuuden mittaamisessa, mitata maapähkinäpohjaisen lisäruuan vaikutusta malawilaisten lasten aktiivisuuteen ja selvittää pienten lasten vanhempien käsityksiä liittyen fyysiseen aktiivisuuteen ja lasten kehitykseen.

Ensimmäisessä osatutkimuksessa 56 malawilaista lasta, jotka olivat 16.0—18.5 kuukauden ikäisiä, pitivät viikon ajan ActiGraph GT3X –merkkistä kolmisuuntaista kiihtyvyysmittaria. Tutkimusapulaiset kävivät lasten luona päivittäin tarkistamassa kuinka lapsi piti mittaria. Viikon mittaamisjakson aikana tutkimusapulaiset videokuvasivat lapsia kaksi kertaa vapaan leikin aikana. Vertailimme kiihtyvyysmittareiden lukemia Children's Physical Activity Form –menetelmällä koodattuun observoituun aktiivisuuteen. Lisäksi analysoimme laitteen rekisteröimän mittausajan jättämällä pois mittausviikon ensimmäisen ja viimeisen päivän, yöajan ja vähintään 20 minuutin mittaiset jaksot, jolloin laite antoi 0-lukemia. Toisessa osatutkimuksessa 1932 malawilaista lasta satunnaistettiin viiteen interventio- ja yhteen kontrolliryhmään. Interventioryhmissä olevat lapset saivat 10—40 g maapähkinäpohjaista lisäruokaa (lipid-based nutrient supplement, LNS) päivittäin 6 kuukauden iästä 18 kuukauden ikään. Lasten aktiivisuus mitattiin ActiGraph GT3X+ –kiihtyvyysmittarilla interventiojakson lopuksi. Kolmannessa osatutkimuksessa haastattelimme kuuttatoista vanhempaa ja kahta avainhenkilöä teemahaastatteluissa sekä kuutta vanhempaa ryhmähaastattelussa.

Ensimmäisen osatutkimuksen 52:sta mittausaika-analyysiin otetusta lapsesta 79 prosentilla (95 % luottamusväli 65—89 %) oli riittävästi mittausaikaa. Riittävänä aikana pidimme vähintään neljää päivää, joissa jokaisessa oli ainakin 10 tuntia mittausaikaa. Toisessa osatutkimuksessa vastaava luku oli 60 % (95 % luottamusväli 58—63 %) 1339:sta aktiivisuusmittaukseen osallistuneesta lapsesta. Ensimmäisen osatutkimuksen huoltajista 70 % ja toisen osatutkimuksen huoltajista 96 % oli sitä mieltä, että mittaus sujui hyvin.

Ensimmäisessä osatutkimuksessa kiihtyvyysmittarin aktiivisuuslukemat nousivat sitä mukaa kuin observoitu aktiivisuustaso kasvoi. Erot olivat tilastollisesti merkitseviä kevyen ja reippaan aktiivisuusluokan välillä kaikissa mittaussuunnissa ja kolmen mittaussuunnan kiihtyvyyden resultantissa. Paras osuvuus reippaan ja rasittavan aktiivisuuden erottamiseen kevyemmästä aktiivisuudesta oli resultantin raja-arvolla 208/15 s ja pystyakselin raja-arvolla 35/15 s. Toisissa videokuvauksissa observoituun aktiivisuuteen verrattuna resultantin raja-arvo osoitti 94,2 % sensitiivisyyttä ja 90,9 % spesifisyyttä erottamaan reippaan ja rasittavan aktiivisuuden kevyemmästä aktiivisuudesta. Vastaavat lukemat pystyakselin raja-arvolle olivat 84,1 % ja 84,6 %.

Toisessa osatutkimuksessa kontrolliryhmän lasten aktiivisuuslukemat olivat vähän alhaisempia kuin interventioryhmissä olleiden lasten, mutta erot eivät olleet tilastollisesti merkitseviä. Tulokset pysyivät pääosin samanlaisina kun taustamuuttujat vakioitiin.

Kolmannessa osatutkimuksessa sekä lasten vanhemmat että avainhenkilöt pitivät fyysistä aktiivisuutta lapsen positiivisena ominaisuutena. Vanhemmat kuvailivat aktiivisia lapsia sellaisiksi, jotka oppivat sekä käytännön asioita että kognitiivisia taitoja aikaisessa vaiheessa, olivat sosiaalisesti kyvykkäitä, pysyivät terveinä ja liikkuivat paljon. Aktiivisuus sopi hyvin yksiin niiden kehitystavoitteiden kanssa, joita vanhemmilla oli lapsille. Vanhempien mukaan aktiivisuutta lisäsivät tasapainoinen ruokavalio, hyvä terveys ja stimulaatio.

Loppupäätelmänä voidaan todeta, että ActiGraph –kiihtyvyysmittari on käyttökelpoinen ja validi menetelmä mittaamaan taaperoikäisten lasten aktiivisuutta. Tuloksemme eivät tue hypoteesia, jonka mukaan LNS-ravintolisä 10—40 gramman päiväannoksina lisäisi malawilaisten lasten fyysistä aktiivisuutta. Malawilaiset vanhemmat käsittävät aktiivisuuden sekä lapsen fyysisenä että psyykkisenä ominaisuutena.

Contents

Abbreviations

CI	Confidence interval
CARS	Children's Activity Rating Scale
CPAF	Children's Physical Activity Form
FGD	Focus group discussion
HFIAS	Household Food Insecurity Access Scale
HAZ	Height-for-age z-score
IDI	In-depth interview
iLiNS-DOSE	A study of the International Lipid-Based Nutrient Supplement Project: Prevention of linear growth failure in infants and young children with lipid-based nutrient supplements
IQR	Interquartile range
LAZ	Length-for-age z-score
LNS	Lipid-based nutrient supplement
LPA	Light physical activity
MET	Metabolic equivalent
MVPA	Moderate-to-vigorous physical activity
OSRAC-P	Observational System for Recording Physical Activity in Children-Preschool Version
ROC	Receiver operating characteristic
ROC-AUC	Receiver operating characteristic curve, area under curve
SD	Standard deviation
VM	Vector magnitude
VPA	Vigorous physical activity
WAZ	Weight-for-age z-score
WHZ	Weight-for-height z-score
WLZ	Weight-for-length z-score

List of original publications

This dissertation is based on the following original papers, referred to in the text by their roman numerals I-III

I	Pulakka A, Cheung YB, Ashorn U, Penpraze V, Maleta K, Phuka JC, Ashorn P. Feasibility and validity of the ActiGraph GT3X accelerometer in measuring physical activity of Malawian toddlers. Acta Paediatrica 2013; 102: 1192-1198.
II	Pulakka A, Ashorn U, Cheung YB, Dewey KG, Maleta K, Vosti SA, Ashorn P. Effect of 12-month intervention with lipid-based nutrient supplements on physical activity of 18-month-old Malawian children: a randomised, controlled trial. European Journal of Clinical Nutrition 2015; 69: 173-178.
III	Pulakka A, Ashorn P, Gondwe A, Phiri N, Ashorn U. Malawian parents' perceptions of physical activity and child development: a qualitative study. Child: Care, Health and Development (e-pub ahead of print, doi: 10.1111/cch.12218)

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1 Introduction

Undernutrition is a significant global problem which, by estimate, contributed to 3.1 million child deaths in 2011 (1). Undernutrition encompasses a variety of conditions, including chronic undernutrition, acute undernutrition and micronutrient deficiencies (1,2). Most common of these is chronic undernutrition, which affected 165 million children in 2011 (1). Chronic undernutrition is typically defined in terms of stunted linear growth (1,2) and it is a risk factor for several adverse outcomes, such as increased morbidity and mortality as well as poorer cognitive ability and educational attainment (1,3-5).

Improved nutritional status of young children has been targeted with several interventions, many of which aim at improving complementary feeding at the age of 6 to 23 months (6). The effects of these interventions are typically measured by variables related to growth, such as weight or height gain, morbidity, micronutrient intake and behavioural development (7). These indicators have some limitations. Growth, morbidity and developmental indicators are not specific to nutrition (8) while assessing micronutrient intake requires considerable resources in obtaining, storing and analysing the samples.

Physical activity might serve as an additional indicator of healthy growth. In young children, physical activity is commonly present in form of play (9). Play is important for the psycho-social well-being and motor development of the children (10,11). Studies have shown that undernourished children are less physically active than well-nourished children, but increase their activity as their nutritional status improves (12-14). In addition, interdependence between undernutrition and physical activity is not yet completely understood. Diversion of energy from some complementary nutrient supplements to physical activity instead of growth has been suggested as one of the possible explanations for limited growth response (15,16) but the data from physical activity is limited.

Detailed and accurate measurement of physical activity is a complex undertaking (17). During the past years, objective measurement of physical activity has become more feasible in large-scale studies by using accelerometers (18,19). Accelerometers are small devices that measure acceleration caused by body movement and they are typically worn on hip over several days (18). Their use is currently reaching child populations in high-income countries (18), but they are still very infrequently used in low-income countries (20,21). The advantages of accelerometers include unobtrusiveness, small participant burden and provision of rich and objective data (18,22). However, accelerometers are not "plug and play" devices, but researchers need to make a number of decisions regarding to the type of accelerometer, outcomes used and data reduction (22,23). Furthermore, accelerometers need to be calibrated and validated in the target population before use (9,24), but validation studies are lacking among children who are recipients of complementary feeding interventions, i.e. children under two years of age who reside in food insecure areas.

Young children live under parental supervision. Parental encouragement for physical activity is associated with the toddlers' and preschool aged children's physical activity (25,26). Understanding lay perceptions of issues related to public health, in this case the parental perceptions on physical activity, is important in developing culturally appropriate measurement tools and in disseminating information of studies (20,27-29).

This study focused on physical activity of Malawian toddlers who live in a food insecure area. We assessed an accelerometer method in measuring physical activity, measured effects of a nutrient supplementation with lipid-based nutrient supplement (LNS) on physical activity and explored perceptions of parents of young Malawian children toward physical activity and child development.

2 Review of the literature

2.1 Approach to the literature review

The aim of the literature review is to provide background information for the current research. The review includes definition of physical activity and undernutrition, description of physical activity and its measurement among young children and current view to interrelationship between undernutrition and physical activity.

The literature was searched primarily from Medline using Ovid interface and secondarily through Medline through PubMed interface and Scopus. Additional searches were done through Google Scholar. The main search terms included, but were not limited to, physical activity/motor activity, accelerometer/accelerometry, parental perceptions/perspectives, undernutrition and sub-Saharan Africa/Africa south of Sahara. The reference list of the relevant literature was then further reviewed. National and international reports and guidelines were also included when relevant. The last searches were done from May 2014 through December 2014. Emphasis was given to recent publications and primary data, but in relevant parts, such as definitions or overall description, review articles were used. Where possible, the literature was limited to toddlers, i.e. children aged 1 to 3 years. When this strategy resulted in very few studies, the search was expanded to children under 5 years of age.

2.2 Physical activity in young children

2.2.1 Definition and national recommendations

In scientific literature, physical activity is ordinarily defined as "*any bodily movement produced by contraction of skeletal muscle that substantially increases energy expenditure*" (30,31). The substantial increase of energy expenditure usually refers to increase above resting values (32). Total energy expenditure is comprised of three components: resting metabolic rate, physical activity and thermic effect of feeding (33). The largest component is resting metabolic rate (about 65%), the second largest physical activity (15 to 30%) and the smallest is the thermic effect of feeding (about 7 to 13%) (33). Physical activity is the most variable component of the total energy expenditure (34). Energy expenditure is expressed in metabolic equivalents (METs), where one MET denotes the resting metabolic rate of about 3.5 ml O_2 x kg^{-1} x min^{-1} (32,34,35).

Physical activity is typically categorised according to its intensity in sedentary behaviour, light physical activity (LPA), moderate physical activity (MPA) and vigorous physical activity (VPA) (Figure 1) (36). These categories can also be combined as moderate-to-vigorous physical activity (MVPA) or light-to-vigorous physical activity (Figure 1). In addition to intensity, physical activity can be expressed based on its mode or type (e.g. walking, running, bicycling) or domain (transport, leisure, occupation) (17,30,36-38). Physical activity can also be categorised based on days of the week into weekday and weekend day activity (30).

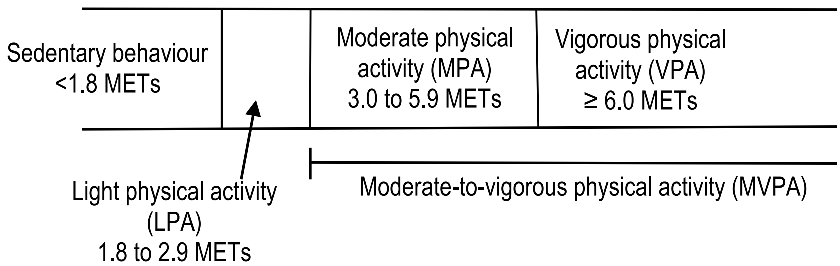


Figure 1. Categorisation of activity intensities according to the metabolic equivalents (METs) (36,38)

There are three other terms that are distinct from physical activity although they sometimes are used interchangeably: sedentary behaviour, physical fitness and exercise. Sedentary behaviour is defined as "*any waking behaviour associated with energy expenditure ≤1.5 METs while in a sitting or reclining posture*" (39). Sedentary behaviour is considered separate from the lack of MVPA because there is little association between the two (39-41). Most common sedentary behaviours for children include television viewing, video game playing and travelling by motorised transport (40,42-44). Physical fitness, on the other hand, is a set of attributes that people have or achieve and that relate to their ability to perform physical activity (30,31). These attributes include cardiorespiratory endurance, skeletal muscle strength, flexibility, reaction time and body composition (30,31). Exercise or exercise training can be defined as "*a subcategory of leisure-time physical activity in which planned, structured and repetitive bodily movements are performed to improve or maintain one or more components of physical fitness*" (31,35). Exercise, therefore, is part of physical activity, but not all physical activity is exercise.

Physical activity of an infant increases steadily throughout the first two years of life (45). After peaking at preschool age or at early school years, physical activity levels decline as the age of the child increases (10,35). Physical activity continues declining from childhood through adulthood, and the decline is especially steep from childhood through adolescence (46,47). In childhood, physical activity of girls declines more than boys (35). Some of this difference can be attributed to lower levels of exercise play, and especially rough-and-tumble play, in girls than in boys (10).

Table 1. Examples of national physical activity guidelines for toddlers.

Country	Authority/working group	Age range	Recommendations/guidelines for minimum daily physical activity
US	National Association for Sports and Physical Education (48)	1 to 3 years	- 30 minutes of structured activity - From 60 minutes up to several hours of unstructured activity
Canada	Canadian Society for Exercise Physiology, with assistance from multiple partners (49)	1 to 4 years	- 180 minutes of physical activity at any intensity - Including a variety of activities in different environments and activities that develop movement skills
Australia	The Department of Health (50)	1 to 5 years	- 3 hours, spread throughout the day
Ireland	National Physical Activity Guidelines Steering Group (51)	2 to 18 years	- 60 minutes at moderate to vigorous level - Should include muscle-strengthening, flexibility and bone-strengthening exercises 3 times a week
UK	The Department of Health (52)	<5 years, capable of walking	- 3 hours, spread throughout the day
Finland	Ministry of Social Affairs and health (53)	<7 years	- 2 hours of brisk activity - Should include training of fundamental motor skills in various settings and in a diversified way

Several countries have developed national guidelines or recommendations on how much toddlers, i.e. children between one and three years of age, should engage in physical activity (Table 1). Most of these recommendations are based on self-reported physical activity (54). The minimum recommendations for toddlers aged 1 to 3 years vary between 1.5 hours and 3 hours daily (48-53). According to the recommendations, toddlers should engage in varied intensities and types of activities including both free play and structured activities aimed at developing motors skills (49-51,53).

2.2.2 Health and developmental effects of physical activity in children

Physical activity can benefit both current and future health of children (55). Although evidence of association between physical activity and reduction in the risk of many non-communicable diseases, such as cardiovascular diseases (41,56-58), certain cancers (57,59,60) and mental health problems (61) is convincing, most of the measures come from late childhood or early adolescence (62). A systematic review by Timmons and colleagues on physical activity and health at ages 0 to 4 years found low- to high-quality evidence of positive association between higher physical activity and better measures of adiposity, bone and skeletal health, motor skill development, psychosocial health, cognitive development and aspects of cardiometabolic health (63). However, only one of the reviewed studies included toddlers and it concluded with no beneficial effect of increased physical activity on bone mass accretion (64). Another recent study found inverse association between physical activity and cardiovascular disease risk factors in boys aged 2 to 6 years, but not in girls (65). For older children (6 to 9 years), the inverse association was also found in girls (65).

Because fundamental motor skills are developing during the toddler period (9,45,66), considering the interrelationship between physical activity and motor skills is important. Although there are several studies suggesting positive (67-70) or marginally positive (71) association between physical activity and motor skills competence, the evidence again mostly comes from pre-schoolers. It is also difficult to establish the direction of the association: it might well be that toddlers who are physically active gain better motor skills or, conversely, that better motor skills allow toddlers to be more physically active (72,73). For pre-schoolers, there is some evidence supporting the latter, i.e. that development of motor skills competency promotes physical activity (73-76). In general, physical activity and motor skills development have dynamic and synergistic relationship, which may form a positive feedback loop where increasing the other will lead to improvements in the other (77).

As physical activity in young children commonly takes place in the form of play (78), it can have benefits other than those for physical health (11,79,80), although the evidence of association between physical activity by itself and psycho-social well-being is currently limited (81). Some of the fundamental characteristics of play include pleasure, freedom, creativity, adventure and risk (80). Playing is indeed considered so important that it has been declared a fundamental right of every child in the United Nations Convention on the Right of the Child (82).

Play has the potential to improve children's emotional, social and cognitive well-being (83) and it is beneficial to the development of healthy brain (11,84). Although little studied, playing may improve emotional well-being of children (83,85,86). As Burdette coins it: "*it is the happiness that children can achieve through play that might be the most important message to communicate to parents about the benefits of physical activity of children*" (83). Playing also helps to build bonds within the family and with peers (83,84,86,87). It helps in developing social skills, such as cooperating with others and doing compromises, and it may improve social and emotional capabilities such as empathy, self-regulation and flexibility (83,87). Playing with parents who express sensitivity, positive regards and cognitive stimulation has been associated with improved language and cognitive development in toddlers (88). By providing children with flexible approach to their environment, playing can also improve children's problem-solving and divergent thinking abilities (86).

Moreover, good health behaviours, such as being physically active, may carry over from childhood into later life. This concept of stability of behaviours, or maintaining relative rank or position within a group, is called "tracking" (89). Evidence suggests that tracking of physical activity from early childhood to middle childhood is low or moderate (89,90). Level of tracking from childhood to adulthood varies from low to high (91,92). Tracking is more evident over short periods of time than over longer periods (93). These findings reinforce the importance of promoting physical activity of toddlers because establishing active lifestyle in early childhood can have sustained benefits later in life.

2.2.3 Activity patterns in children

Physical activity patterns change markedly during early childhood, from birth to 5 years of age (9,94). *Infancy* encompasses the first 12 months of life (45). During the first six months of infancy, activity is restricted to reaching and grasping objects whereas during the latter 6 months, the infants learn rudimentary movement skills (9,45). Crawling at 4 to 8 months of age and creeping at 7 to 11 months of age precede the onset of locomotion (66). Walking usually commences by the end of the first year or at the beginning of second year of life (9,66). During the toddler period, ages 1 to 3, children become more proficient in locomotor skills such as running and jumping (9,45). They also experiment with object control skills, which encompass kicking, throwing and catching (9). Locomotor skills and object skills together form the fundamental motor skills (73). Preschool years, from the age of 3 to 5 years are characterised with increasing stability in locomotor and further development of object-control skills (9,45).

Typical physical activity of young children aged from 0 to 5 years is in form of free play (9). Physical activity play can appear in three forms: rhythmic stereotypes, exercise play and rough-and-tumble play (10). Rhythmic stereotypies are gross motor movements without observable goals (10,66). Exercise play refers to gross locomotor movements in the context of play which starts at the end of the first year and peaks at 4 years of age. It can be either solitary or social with parents or other children (10). Rough-and-tumble play is aggressive-resembling vigorous behaviour, but in a playful context (10). This can include wrestling, kicking and tumbling and it is mostly done with other children but also with parents (10). Rough-and-tumble play increases through preschool year and peaks at around 8 or 10 years of age, and then declines (10). In addition to play, in high income settings, toddlers and pre-schoolers can also attend structured activities such as swimming lessons, children's gym or organised sports (9).

Physical activity of young children typically includes sporadic short bursts of MVPA, punctuated by periods of lower intensity activity and rest (9,78,95,96). The sporadic nature of children's physical activity was demonstrated in a study of fifteen Californian children aged 6 to 10 years, where 95% of the high intensity activities lasted less than 15 seconds with median duration of 6 seconds (97). Moreover, an important characteristic affecting the activity patterns of infants and toddlers especially, are daytime naps (9,98,99). In toddlers, the daytime naps can take from 0.5 to three hours in a day (9).

Several studies have measured physical activity of toddlers, all of them in high-income countries in Europe and Australia (Table 2). Only two of the studies, based on observation and parental report, were reported before this PhD project was commenced (100,101). Several of the studies indicated low physical activity levels among toddlers (99-104), but the differences in methodology make it difficult to compare the findings. As an example, the two studies that used accelerometers in determining whether the children met the physical activity recommendations of 3 hours of physical activity per day, concluded with almost opposite results: in the Australian study 91% of the toddlers met the recommendations (98), whereas in the Dutch study none of the toddlers met the recommendations on weekdays (104). The difference is likely due to the different count cut points for physical activity intensities used in the studies. The Australian study used lower cut points that had been validated with toddlers (105) and resulted in higher estimates of MVPA than the higher cut points originally developed for 3-year-old children (106) used in the Dutch study.

Table 2. Studies measuring physical activity of toddlers aged 1 to 3 years

Study	Participants	Age	n	Activity assessment	Results
Australian Bureau of Statistics 2014 (107)	Representative sample of the population living in private dwellings in selected regions of the country	2 to 4 years	877	Adult report of the child's activity during the past 7 days	- Met the recommendations of 3 hours of activity during the past 7 days: 72%. - Mean time spent on physical activities: 3.3 hours/day indoor and 2.9 hours/day outdoor.
Gubbels et al. 2011, the Netherlands (102)	Randomly selected children from nine child-care centres in Maastrict	Mean 2.6 years	175	Observation with OSRAC-P, 8 x 15 s observation	- Indoor observations: 59.4% of the time sedentary, 5.5% MVPA. - During outdoor observations: 31.2% sedentary, 21.3% MVPA
Hnatiuk et al. 2012 (InFANT study), Australia (98)	Children of first-time parents attending existing parent groups within Melbourne area	Mean 19.1 months (SD 2.3)	295	ActiGraph GT1M, for minimum of 4 days	- LPA mean 184.5 min/day, MVPA mean 47.9 min/d. - Met guidelines of minimum of 180 min light-to-vigorous activity per day: 90.5%.
Johansson et al. 2015 (Early STOPP study), Sweden (96)	Children of overweight and normal weight parents from paediatric health centres	Mean 2.03 years (SD 0.1)	138	ActiGraph GT3X+ for minimum of 4 days (wrist placement)	- Sedentary: 432 min/day (55%) - Low-intensity activity 265 min/day (34%) - High-intensity activity 84 min/day (11%)
Klesges et al., 1986, US (100)	Children from a paediatrics clinic and local YMCA	22 to 46 months (mean 30.5)		Observation with FATS, 1 hour	- During observation: 43% sitting, 33% standing, 13% walking

Manios 2006 (The GENESIS study), Greece (101)	Children from randomly selected nurseries/day-care centres in five counties	12 to 24 months	207	Parental report	- Mean light to vigorous physical activity 1.45 hours/week (SD 3.15) for boys and 1.02 hours/week (SD 2.29) for girls
Scholes & Mindell 2013 (Health Survey for England), UK (103)	Representative sample of the population living in private households in England	2 to 4 years	418	Parental report of the child's activity over the last week	- Reached the guidelines of minimum of 3 hours of physical activity per day: 9% - From 60 to 179 min of physical activity/day: 7% - Low activity: 84%
Van Cauwengerghe et al. 2011, Belgium (99)	Children from 11 randomly selected and consented child care centres in Ghent	Mean 20 months (SD 4 months)	47	ActiGraph GT1M accelerometer for minimum of 3 days. Observation with OSRAC-P, from 19.5 to 60 minutes	- Mean accelerometer counts: 137 (SD 199) /15 s - During observations: 50.4% sedentary, 36.3% light, 13.3% MVPA
Wijtzes 2013 et al. (Generation R study), the Netherlands (104)	Originally invited: children of all pregnant women in Rotterdam, a subsample included in this study.	Mean 25.1 months (SD 1.1)	347	Accelerometer, ActiGraph 7164 for 1 weekday and 1 weekend day	- Weekdays: 85.6% sedentary, 9.6% LPA, 4.8% MVPA. - Weekend days: 84.5% sedentary, 10.3 LPA, 5.2% MVPA. - None reached the guideline of 3 hours/day on weekdays, 1 reached it on weekend days. 24% reached 1.5 hour/d on a weekday, 30% reached it on a weekend day.

FATS, Fargo Activity Timesampling Survey ; LPA, light physical activity; MVPA, moderate-to-vigorous physical activity; OSRAC-P Observational System for Recording Physical Activity in Children-Preschool Version; SD standard deviation

2.2.4 Determinants of toddlers' physical activity

Determinants of toddlers' physical activity can be classified to different domains: demographic and biological; psychological, cognitive and emotional; behavioural; social and cultural; and physical environmental (108). Gender and age are most studied demographic and biological variables. Several studies have indicated that boys are more active than girls (25,100,101,104,109-111) and older toddlers or pre-schoolers more active than younger toddlers (25,104,110-112), although some studies have reported no sex or age difference in activity (96,98,102,113). Two studies that tested correlation between a behavioural variable, TV viewing, with physical activity of toddlers did not find correlation (104,110). No correlation was also found for TV viewing and physical activity or sedentary behaviour of pre-schoolers (114).

Several social and cultural variables seem to be determinants of toddlers' physical activity. Time spend with other babies of a similar age at 4 months of age (115) and having two or more siblings (104) have been associated with higher levels of physical activity. Toddlers who interact with adults, such as spend time being physically active with mother and who receive parental or preschool staff's support on physical activity have also been found to be more physically active (25,100,102,115). Parental support has showed positive association with parent-reported physical activity of toddlers (25,116). From physical environment variables, time spent outdoors, having access to play equipment and summer or spring season in cold environments have been associated with higher physical activity levels (104,109,110,113,117).

2.2.5 Physical activity of children in sub-Saharan Africa

No studies on toddlers' physical activity in sub-Saharan Africa were found, but some studies have reported physical activity of school-aged children. The ISCOLE study group objectively measured children's physical activity in 12 countries, including Kenya and South Africa in sub-Saharan Africa (118,119). A recent systematic review by Muthuri and colleagues identified 36 studies reporting physical activity of children from 5 to 17 years of age in sub-Saharan Africa (21). Moreover, during the 2014 Global Summit on the Physical activity of Children held in Toronto, Canada, reports on physical activity among children and youth from 15 countries were presented (120). Five of the presented countries were from sub-Saharan Africa, namely Ghana, Kenya, Mozambique, Nigeria and South Africa (121-126).

In the ISCOLE study, 9 to 11-year-old children in the urban sites of Nairobi, Kenya and Cape Town, South Africa, had mean (SD) time of 71 (31) minutes and 65 (26) minutes of MVPA per day, respectively (119). That was more than the mean MVPA time of 60 (SD 25) minutes/day in the total sample of 12 countries from a variety of income classes (119).

Based on the reports presented in the 2014 Summit on the Physical activity of Children, the level of school-aged children's overall physical activity varied widely sub-Saharan African countries, with grade B (well over half of the children are active) assigned to Mozambique, C (about half of the children are active) to Kenya and Nigeria and D (less than half of the children are active) to Ghana and South Africa (121-126). The high activity levels Kenya, Mozambique and Nigeria were attributed to active transportation (i.e. human-powered transportation, such as walking) and household chores (121,124,126), whereas in Ghana the association was suspected but no evidence was available (123). The variation was also wide in the prevalence of sedentary behaviours (125). Furthermore, in the presented sub-Saharan African countries, only approximately half or less of the school-aged children participated in organised sports or had enough active play (121-126).

Because of the scarcity of high-quality data, the trends of physical activity levels in sub-Saharan Africa are difficult to assess. Muthuri and colleagues reviewed temporal trends of children's physical activity in sub-Saharan African countries (21). Of the studies included, those from years 1999 to 2009 had sample means of ≥2.6 hours of daily MVPA among school-aged children and those from 2012 had sample means of ≤ 1.9 hours of daily MVPA (21). However, the authors draw no conclusions of trends because of the varying methodology in the studies (21).

Evidence suggests that male sex, low socio-economic status and living in rural area could be some of the determinants of high physical activity in school-aged children in sub-Saharan Africa (21,121-124,126). Five of the six studies assessing sex difference in physical activity and included in the review of Muthuri and colleagues reported higher activity levels in boys than in girls (21). Eleven of the 14 studies that reported socio-economic and rural/urban differences in physical activity indicated higher activity of school-aged children with lower socio-economic status and in rural areas than children with higher socio-economic status or in urban areas (21). The higher activity levels of rural children compared to that of urban children were also highlighted in the physical activity reports of Kenya and

Mozambique (124,126) whereas the greater likelihood of rural children using active transportation to school were indicated in the report cards of all the five sub-Saharan African countries (121-124,126).

2.2.6 Parental perceptions of children's physical activity

The attitudes of parents' can influence young children's physical activity (25,26). Parents of young children may define physical activity in a different way as researchers. As mentioned at the beginning of this literature review, researchers and public health professionals view physical activity as any movement of skeletal muscles that increases energy expenditure (30,31), and the recommendations on amount of physical activity often refer to MVPA (51,93). In the study of Dwyer and colleagues, Australian parents of preschool children described physical activity as any form of body movement (127), which is essentially similar to the scientific definition. New Zealander and Australian parents in two other studies perceived physical activity to refer mostly to structured activity or exercise, excluding play from the definition (128,129) whereas Canadian parents included both structured and unstructured activities in the definition of physical activity (130). As typical physical activities for toddlers and pre-schoolers parents listed e.g. walking, running, jumping, climbing, bike-riding, swimming, dancing and different games (127,130,131).

Many studies indicate that parents perceive their toddlers and pre-schoolers to engage in adequate amount of physical activity (130-134). They see physical activity as natural for children and occurring spontaneously (127,132). Parents in the study of Dwyer and colleagues described young children's physical activity as sporadic and of short duration (127). They also did not consider using activity intensities such as light, moderate and vigorous, as applicable because they perceived young children to be either very active or not active at all (i.e. on versus off) (127).

Parents perceive physical activity as beneficial for their toddlers and pre-schoolers and believe that playing has a large role in the children's health and well-being (127,133,134). According to parents, the health benefits of physical activity include increased muscle and bone development, motor skills development, obesity prevention and improvement in sleep (127,131,132). Parents also think that physical activity can decrease behavioural problems, help in learning and make the children more settled after releasing some energy (127,131,132). Learning to be physically active in childhood would, according to some of the parents, facilitate development of long-term healthy lifestyle (130).

Parents also describe worries of negative impacts of physical activity. Physical activity can pose extra demands for the parents and increase the likelihood of injuries (132). According to some studies, parents are worried of over-timetabling young children's days with too many activities as children need a balance between activity and quiet time (127,133,135). Some parents also are concerned of physical activity displacing creative and mental pursuits (132) or consider important that pre-schoolers learn to sit still in preparation for school (133).

Several studies have reported parental perspectives of facilitators and barriers of toddlers' and pre-schoolers' physical activity (127,130-136). The factors, organised under the themes of Social Ecological Model by Bronfenbrenner: child-related factors, interpersonal factors and environment-related factors (136,137), are listed in Table 3.

Table 3. Parental perceptions of facilitators and barriers of toddlers' and pre-schoolers' physical activity

	Child-related (intrapersonal) factors	Interpersonal factors	Environment-related factors
Facilitators	- Active personality trait (127,130,132,134,135) - Gender, boys generally more active (132,134,135) - Movement skills (132,135)	- Parental modelling and encouragement (127,130,132,133,135) - Parental participation in the child's activities (130,132,135) - Siblings, grandparents and sense of social connectedness (127,130,135)	- Attendance in preschool or day care with good facilities (127,130,135,136) - Access to safe playgrounds (127,133,135) - Access to organised activities (127,132,133,135) - Supporting equipment, such as toys, having pets (132,135) - Yard or garden or home in rural area (133,135) - Rules and alternatives to TV viewing (132,135) - Active transport, attending nearby schools. Holidays to active places (132)
Barriers	- Children's preference for sedentary activities (130,136) - Personality and gender (134) - Children's health problems or disability (136) - Young age as barrier for enrolling in organised activities (130)	- Parents' lack of time or work load and tiredness (130-133,135,136) - Parents' lack of knowledge on age-appropriate activities (131,132) - Parents' reluctance to take their child into a park or do activities with the child (133,135) - Some cultural traits, e.g. being overprotective (136) - Social norms related to independent mobility (132) - Family structure/single parents (136)	- Safety concerns, regarding road safety, play equipment and strangers (127,130-133,135,136) - Poor weather: winter, extreme weather, high temperature (130-136) - Difficult access to physical activity areas (132,133,135) - Financial constraints related to organised activities (127,130,133) - Today's society versus how things were earlier (130,132) - Having TV switched on, excessive TV viewing (127,133) - Lack of resources at community or child care (136) - Small yard size at home (132,135)

2.3 Measurement of physical activity

2.3.1 Measurement methods for physical activity

Ideally, a physical activity measurement method should be reliable, valid, feasible and responsive (24,38,138). Reliability refers to reproducibility of the method, i.e. that the same results are free of measurement error and can be obtained even though the assessors are different (24,38,138). Reproducibility further includes two concepts: intra-instrument and inter-instrument reliability (24,138). Validity refers to the ability of the instrument to measure what it is intended to measure (24,38,138). Feasibility of a physical activity measurement method refers to its cost, acceptability and required expertise (24,138). A responsive instrument is able to detect change in physical activity over time (38).

An ideal measurement method for assessing physical activity would measure all dimensions of physical activity, such as type, frequency, intensity and duration (17,37,139). In addition, the method would cause minimal participant burden in regards to comfort of instrument wear and data recording requirements (140). When measuring young children's physical activity, the method should be able to capture sporadic activity as well as most dimensions of activity (36,95).

Measurement methods for physical activity can be categorised in many ways, but most commonly they are grouped into two broad categories: objective (direct) or subjective (indirect or self-report) methods (Figure 2) (36-38,95,139,141-143). In addition, there are methods to assess physical activity through energy expenditure, such as doubly labelled water technique or indirect calorimetry (37,141,143,144), but they are beyond the scope of this dissertation. The decision on what method to use is done on a case-by-case basis depending on the research questions, target group, sample size, available resources, time frame and context (36,142).

To improve the precision, or to utilise advantages of two different methods, physical activity measurement methods can be combined (34,37,54). A typical combination is that of heart rate monitoring and accelerometry (38,143,145), which can also be combined into a single monitor (37). Another combination is accelerometry together with a questionnaire or a diary (143).

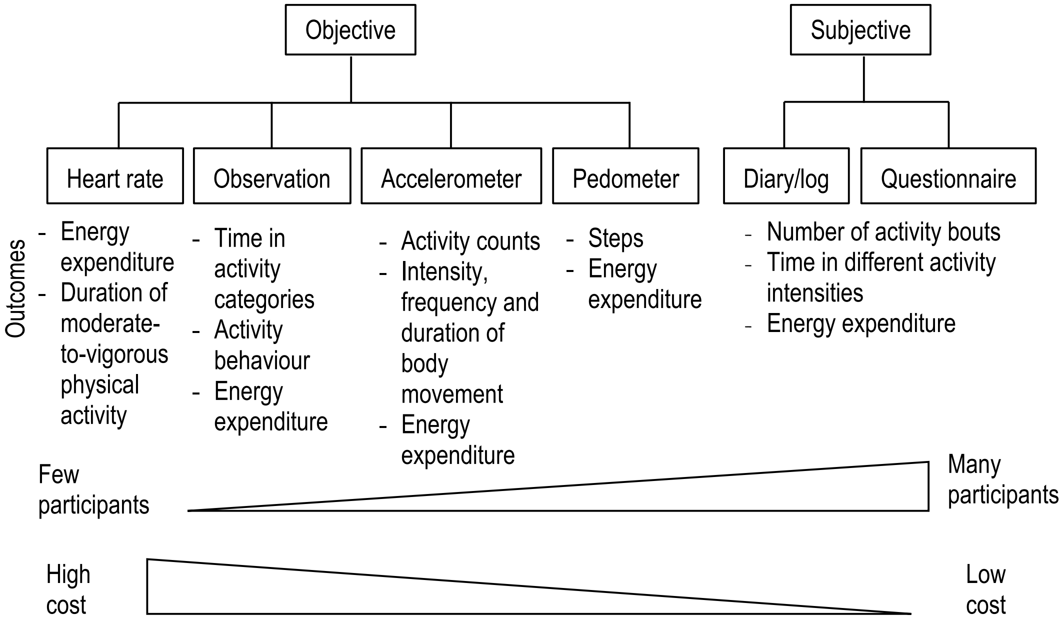


Figure 2. Physical activity measurement approaches. Modified from Dollman et al. 2009 (36) and Warren et al. 2010 (38)

2.3.2 Subjective methods

The most common subjective methods for assessing physical activity are questionnaires and diaries (36,95). They are very widely used, especially with large samples because of their ease of use and low cost (36,142,143,146). Until recently, questionnaires have remained basically the only method available in population-based studies in low- and middle-income countries (20). Although questionnaires and diaries can be filled in as self-reports, in children under 10 years of age they are generally completed by parents or teachers (36-38,95,142).

In addition to low cost, the advantages of subjective methods include their ability to record the specific physical activity behaviour and context (36,38,139). The context of activity can be documented particularly well with diaries (95,147). The disadvantages include risk for recall bias and technical errors, susceptibility to socially desirable responses, low sensitivity to change in activity levels, difficulties in ascertaining activity intensities and duration as well as cognitive demands of recall (38,142,143,148) Self-administered questionnaires cannot be used in populations with low literacy rates (20). Furthermore, questionnaires are very culturally dependent (20,38). When using a questionnaire in another culture it is not enough to only translate the questions into other language but they need to be culturally adapted so that the questions and examples become relevant to the target population (20).

Several physical activity questionnaires have been developed for pre-schoolers, all of which use proxy reports by either parents or teachers (95,146,149,150). The questionnaires have high variability in the recall period and in the number of included questions. The recall period varies between the past 3 to 4 days (95,149) and recalling the "typical" day of the child (146,150). The questionnaires include from one up to several questions regarding the types or duration of activities that the pre-schoolers attend or the overall activity level of the child (95,146,149,150). Self-reports can also be used to record activities in certain contexts, such as during outdoor play (95,146), week/weekend day (149) or they can be in to form of diary e.g. by coding the form and location of activity throughout the day (143,147).

Most of the pre-schoolers' physical activity questionnaires have been validated against accelerometers although direct observation, pedometer and doubly labelled water have also been used as comparison measures (95,146,147,149,150). The results have been modest. Two reviews, from 2007 (95) and 2010 (146) found association between pre-schoolers' physical activity questionnaires and accelerometer readings to be moderate at best, approximately at interclass correlation r=0.4 level. Another review of physical activity measurement methods of children aged 4 to 19 years concluded that while the correlation coefficient between subjective and objective methods varied widely (range: r=-0.56 to r=0.89), the majority of the reported correlations were low-to-moderate (151). The questionnaires and reports generally overestimated physical activity as compared to accelerometers, pedometers and heart rate measures (151).

2.3.3 Objective methods

The most commonly used objective methods for measuring physical activity include direct observation, heart rate monitoring, accelerometers and pedometers (37,38,141). However, direct observation is sometimes classified under subjective measures because of its reliance on human interpretation (95). Some aspects of objective methods are presented in Table 4. Direct observation is generally used when samples sizes are small but heart rate monitoring, accelerometers and pedometers can be used in both small and large samples (36,38). Compliance issues can reduce the final sample when accelerometers or pedometers are used, whereas this is usually not a problem with direct observation (36). Accelerometer data is more complex to manage and interpret than the observation or pedometer data (36,140,152). Objective methods also have generally lower participant burden than subjective methods as they record data electronically throughout the day as opposed for the participant doing the recording (140).

Pedometers are mounted on the waist or hip and count the number of steps taken, which are then summed over certain time, usually a day (17,37,140,142,143). Earlier models of pedometers used mechanical sensors whereas the newer models have piezoelectric sensors (38,95). Pedometers are relatively simple to use and have low cost (140,143,152). The cumulative records of steps taken during a day can be used to estimate physical activity energy expenditure or distance travelled (17,142,143). However, as pedometers measure a step count regardless of the magnitude of the movement and do not usually store minute-by-minute data, they cannot be used to detect activity intensity categories (17,24,140,143). Pedometers also do not provide information about the type, context or duration of physical activity (37,152). Pedometers have been found to correlate strongly (r=0.73) with MVPA captured by accelerometers in children aged 4 to 5 years (153). Correlation coefficients for pedometers against observed activity of pre-schoolers have ranged between 0.59 and 0.86 (95,152).

Table 4. Objective methods for measuring physical activity of children. Modified from Dollman et al. 2009 (36) and Lindsay et al. 2014 (139)

	Accelerometer	Pedometer	Heart rate monitoring	Observation
Sample size	Small to large	Small to large	Small to medium	Small
Cost	Moderate/High	Low	Moderate	High
Measurement time frame	Multiple days	Multiple days	Multiple days	From minutes to hours
Data reduction	Complex	Simple	Complex	Simple
Contextual information	No	No	No	Yes

2.3.4 Observation

In direct observation, a trained observer classifies children's physical activity over a pre-specified length of time (142,152). Observations are typically done in natural settings, such as home or at pre-school, and the observer records free-living activities (142). Observations can be done either as direct or via video recording (142). Typically the observer watches one child at a time, but some group observation methods have also been developed (154,155). The observer uses specific codes corresponding to characteristics of physical activity and records them either by pen and paper or using a computer (142,152).

Several observation methods have been developed for assessing physical activity of toddlers or pre-schoolers, as listed in Table 5. The methods categorise activity in four (156,157) or five (158-161) levels. They use either continuous sampling, where the observed activities are coded continuously, or momentary time sampling, where the observer records the activities at certain time intervals. Observation methods have been validated against heart rate measurement (156,158,159), oxygen uptake (158) and accelerometers (160,162). The validation studies report moderate or high correlation.

Using direct or video-recorded observation to measure physical activity has several advantages. Observation can provide information on the specific type of and context of activity (157,159-161,163). As influence of the environment to children's physical activity is becoming a research priority, the use of observational methods is increasing (37). Observation is particularly useful when assessing activity of young children who cannot report their activity themselves (143,156,158). Observation methods can also be used as criterion methods for validating other measures of physical activity (141). This has been the case with accelerometers, and pedometers (95,152,164). If observers are properly trained and follow the observation protocols, direct observation can serve as a valid method of physical activity behaviour of children (142).

Direct observation also has several limitations. Although observation does not require equipment, it still is burdensome and costly, because it requires trained observers (36,156,158). As observation requires some human interpretation, researcher bias is possible, although stringent observer training is used to reduce it (95). Reactivity can be a problem when observation is used (141,158,159). Reactivity, i.e. change of behaviour of individuals who know that they are being observed may be shown as the observed child talking to or closely watching the observer (159,165). However, reactivity in observation of toddlers appears to be rare based on observers' reports (158,159).

Table 5. Observation methods for recording toddlers' and pre-schoolers' physical activity

Name	Activity categories	Time unit	Location	Age	Validation	Additional comments
BEACHES, Behaviors of Eating and Activity for Children's Health Evaluation System (159)	1) Lying down 2) Sitting 3) Standing 4) Walking 5) Very active	Momentary time sampling at every 60 second	Home and school/pre-school	4 to 8 years	Against heart rate monitoring in 19 children aged 4 to 9 years. Heart rates increased with each activity code increment.	Additional categories for dietary behaviour and associated environmental events
CARS, Children's Activity Rating Scale (158)	1) Stationary - no movement 2) Stationary - with movement 3) Translocation - slow/easy 4) Translocation - medium/moderate 5) Translocation - fast/very fast/strenuous	1 minute, continuous	Variety, e.g. home, playground, day care, school.	2 to 5 years	Against oxygen uptake and heart rate in 25 children aged 5 to 6 years in structured activities. $P<0.05$ (ANOVA) for differences in oxygen uptake or level of heart rate and all CARS levels. Additional validation against an accelerometer (162): median within child correlations between CARS score and Actiwatch accelerometer 0.74.	Assumption: each minute is equally divided into the number of categories recorded by the observer
CPAF, Children's Physical Activity Form (156)	1) Stationary - no movement 2) Stationary - limb movement 3) Slow trunk movement 4) Rapid trunk movement	1 minute, continuous	School physical education class	8 to 10 years	Against heart rate in 36 children aged 8 to 10 years. Pearson correlation 0.64 between activity points and heart rate.	
FATS, Fargo Activity Timesampling Survey (166)	Several: sleeping, lying down, sitting upright, crawling, climbing, standing still, walking and running, with 4 intensity ratings in each.	10 seconds observation, 10 seconds recording	Home	2 to 4 years	Against Large-Scale Integrated Activity Monitor, LSI, in 14 children aged 2 to 4 years. Correlation between composite count of FATS and LSI 0.90.	Additional codes for parent-child interactions

OSRAC-P, Observational System for Recording Physical Activity in Children-Preshool version (161)	1) Stationary or motionless 2) Stationary with limb or trunk movements 3) Slow-easy movements 4) Moderate movements 5) Fast movements + activity types	Momentary time sampling 5 seconds, 2 times/minute	Pre-school	3 to 5 years	Not available	Additional categories for detailed indoor and outdoor social and non-social contextual information
OSRAC-H, Observation System for Recording Physical Activity in Children - Home version (167)	Similar to OSRAC-P	Similar to OSRAC-P	Home	3 to 6 years	Not available	Modified from OSRAC-P to include categories relevant to home environment
OSRAP, Observation System for Recording Activity in Preschools (160,168)	1) Stationary and motionless 2) Stationary with movement of limbs or trunk 3) Slow, easy movement 4) Moderate movement 5) Fast movement	15 seconds observation, 15 seconds recording	Pre-school	3 to 5 years	Against accelerometer in 23 children aged 3 to 5. Correlation between OSRAP mean activity rating and 1) number of accelerometer-assessed vigorous intervals/h 0.67, 2) number of accelerometer-assessed moderate-to-vigorous intervals/h 0.52.	Modified from CARS. Additional categories for location, context, activity type, interactors.
SCAN-CAT, Studies of Children's Activity and Nutrition-Children's Activity Time sampling method of observation (157,163)	1) Stationary 2) Minimal activity 3) Slow movement 4) Rapid movement	10 seconds observation, 10 seconds recording.	Home	3 to 6 years		Additional categories for environment, persons who were present and type of interaction.

2.3.5 Accelerometers

Accelerometers are currently commonly used in measuring physical activity both in research and in consumer applications (9,54). One of the first motion recorders in measuring physical activity of young children were wristwatch-resembling actometers used by Eaton and colleagues in 1980s and 1990s (169). However, substantial increase in accelerometer use, especially in children, has taken place rather recently as they have become more available, cheaper and with better technical capacities (18,54). Accelerometers have also shown to be feasible in large studies with several thousands of participants, including children (19,47,170).

Accelerometers measure acceleration produced by body movement (138,145,171). What body movement they measure depend on which part of the body they are attached to (18,145). Table 6 lists some of the commercially available monitors. The most commonly used accelerometers belong to the ActiGraph and Actical families (18,140,171).

Table 6. Examples of commercially available accelerometers

Accelerometer type	Examples of commercial devices
Uniaxial	MTI ActiGraph 7164 (also referred to as CSA)
Two-axial	ActiGraph GT1M, BioTrainer, Step-Watch Activity Monitor
Tri-axial	ActiGraph GT3X, ActiGraph GT3X+, Tritrac-R3D, RT3
Omnidirectional	Actical, Actiwatch

Accelerometers can be uniaxial, two-axial, tri-axial or omnidirectional (Table 6) (18,24). Uniaxial accelerometers measure acceleration on one plane, which on hip placement is the vertical axis (24). Tri-axial accelerometers measure acceleration on three orthogonal planes: vertical, horizontal and antero-posterior (24). The output from tri-axial monitors includes information about each of the dimensions separately as well as a three-axial vector magnitude (VM), which is a composite measure of the three dimensions (18). Omnidirectional accelerometers commonly are most sensitive in the vertical plane but record movement also in other directions and thus offer a composite of different signals as an output (18,152).

Most of the older accelerometers use piezoelectric sensors which comprise the piezoelectric element and a seismic mass (145,171,172). When these sensors undergo acceleration, the seismic mass causes the piezoelectric element to bend or compress which then leads to charge variations that can be formed into voltage signal output (145). These voltage signals are proportional to the force of acceleration (145,171). While piezoelectric accelerometers are reliable in detecting dynamic events, they are not well suited for measuring static component of acceleration, which in practice means that they cannot detect body postures (145). Many of the newer devices use microelectromechanical systems, such as capacitive accelerometers which can detect both static and dynamic acceleration and thus are capable of providing information on the inclination of the device (171,172). In capacitive accelerometers, changes in acceleration are detected through variations in the sensors' electric charge storage potential, i.e. through changes in capacitance of the sensing element (171).

The mechanisms of the sampling itself and the post-sampling processes have an impact on the accelerometer output (145,171,172). The sampling rate of the devices can vary substantially, from 1 Hertz up to about 100 Hertz (145). Frequency of human movement occurs usually below 8 Hertz, with the upper limit being about 25 Hertz (145). The accelerometers should have a sample frequency of at least twice of that (145). After sampling, the output usually goes through a band pass filter which aims to attenuate very low and very high frequencies that are not within the range of normal human motion (145,171). As a limitation, narrow filtering range could cause incomplete data collection in physical activities that are outside the range (145,171,172). The filtering ranges are typically somewhere between 0.25 and 7 Hertz (145). In addition, the manufacturer-specified restrictions usually limit the detection of acceleration that are outside the range of human movements, e.g. between 0.05 g and 0.5 g (145). Finally, the signal passes through analogue-to-digital converter, which converts the analogue voltage signals into digital series of numbers, and reaches the processor which applies different analytical approaches to form accelerometer counts (145,171). The accelerometer counts per user-specified unit of time, i.e. epoch, is how most of the current accelerometers report their outcomes (172).

There is no compelling evidence suggesting that one accelerometer model is more valid or reliable than another (23,138). Although tri-axial monitors intuitively would give more valid information than uniaxial, the evidence suggests that in children and adolescents both models provide comparable data (173-176). In the absence of superiority of one model, the choice of accelerometer model can be done based on the objective of the study, resources available, reliability of the model and comparability with earlier studies (22,138) The choice is also somewhat related to the practical features of the device, such as cost, battery life, monitor size and availability of technical support (18,23), although newer models have usually overcome the problems such as small memory storage (172). When using accelerometers to study young children, important factors might be the size and durability of the device and whether it is tamper-proof and validated in the population in question (9).

As an objective and direct measure of physical activity, accelerometers have several advantages. Accelerometers are small, non-invasive and only minimally intrusive and they cause small participant burden (140,145,152). They have proven to be technically reliable and durable, with acceptable number of lost units even in large-scale studies (22). The new microelectromechanical system accelerometers have long monitoring time, low power consumption, data on multiple axes, good affordability and, in some cases, ability to measure orientations (172). In addition, children express little reactive behaviour when wearing accelerometers (18,152). However, a recent study suggest a possibility of reactivity in pre-school children as the activity counts were almost 10% less on the fourth measurement day as compared to the first day of measurement (177). Accelerometers provide rich data that can be used to estimate total or physical activity energy expenditure, duration and frequency of activity intensities, step counts, prevalence of meeting activity guidelines and patterns of activity (22).

The limitations of accelerometers relate to the technology itself, use of the data by researchers and compliance (18). Accelerometers have limited ability to measure non-weight-bearing activities, such as cycling or upper body movement and they underestimate the energy cost of walking on an incline or carrying heavy loads (22,38,152). Some of the accelerometers are not waterproof, thus they need to be removed for water-based activities (38). In addition, accelerometers do not provide information on the context of activity (22,152). They also do not distinguish between the causes of the movement, therefore they may overestimate activity in infants who are frequently lifted and carried by their caregivers (178,179). Currently the output of different models of accelerometers are not comparable with each other (34). Furthermore, the substantial volumes of data in large-scale studies require time-consuming post-processing as data reduction and quality control procedures are currently not well automated (22).

Some of the questions related to use of the data by researchers, i.e. choices for data collection and reduction, placement of the device, sampling interval (epoch), data exclusion, amount of data needed and outcomes used are listed in Table 7. There is no consensus on which data collection and reduction methods to use

(9,54,138) although data reduction criteria can have substantial impact on the outcomes of the study (180). The choice of methods depends on the type and aim of the study as well as the study population (9). To reach a consensus would be even more important currently as analysis methods develop to include more complicated algorithms (54).

Compliance issues, especially participant refusals and device removals, form one disadvantage of accelerometers (22,54). It is also difficult to estimate non-compliance from accelerometer output because consecutive zero counts might imply either removal of the device or the participant being totally sedentary (181,182).

A way forward to improve accelerometer-derived activity estimates could be increased use of raw accelerometer data, possibly using standard units, such as gravitational constant (172,181). Providing that a consensus on data filtering procedures would be reached, using raw acceleration signals would enable comparability of sensor output across manufacturers (34,181). Recent advances in machine-learning techniques and pattern recognition combined with new accelerometer models that capture and store raw acceleration signals in high frequency have offered possibilities for novel approaches to accelerometer data analysis (54). The new models might offer more detailed estimates about activity types and intensities, energy expenditure and body postures (181,183,184).

To improve accuracy and precision of accelerometer data, they can also be combined with data from other sources. Raw acceleration data can be combined with data from heart rate monitor or gyroscope to provide more detailed information about activity (54). Using global positioning system together with accelerometer data can complement the measurement of physical activity by adding information e.g. on context or speed of locomotion (34,181). However, adding global positioning system data would increase complexity of data collection and analysis, raise costs and limit monitoring indoor activities (34). Another way to improve energy expenditure estimations and information about activity type from accelerometers would be to use multiple accelerometers simultaneously (181,185,186).

Table 7. Choices related to accelerometer data collection, cleaning and reduction

Placement	- Right hip typical (9,38), left hip (187) and back (188) might yield statistically similar results with uniaxial devices whereas placing the device in front of the umbilicus may result to higher counts than on hip (189). - Wrist, ankle, upper arm, and thigh placing also used (22,54), although wrist might produce less accurate energy estimates than hip placement (185,190). - Combination of accelerometers worn simultaneously on two different placements, e.g. hip and wrist, can improve estimations (185).
Sampling interval, i.e. epoch	- Traditionally 1 minute, recently shorter epochs (e.g. 1 or 15 seconds) have been recommended to capture children's short bursts of activity (9,18) as the longer epochs can generally underestimate time in MVPA (191,192). - Others argue that the differences in time in MVPA obtained by longer or shorter epochs might be minimal in pre-schoolers (193,194).
Data exclusion	- Varied practices for excluding non-wear time, from 10 minutes to 180 minutes of consecutive zero counts (18,180). Long thresholds of 90 or 180 minutes suggested for adults and adolescents (182,195) but 20 minutes relatively common for children >5 years (9). - Implausible counts sometimes excluded: mean counts/day >3 SDs or <3 SDs of the sample mean or below a certain cut point (196,197)
Data needed for a valid day	- 10 hours per day commonly used (22,198), but the practises vary from one up to 17 hours per day (180). - The 70/80 rule: defining standard measurement day as the length of the time in which ≥ 70% of participants wear the monitor and using 80% of that as minimal time per day for inclusion (199). This has resulted in 7.4 to 7.7 h/day wear-time for toddlers (98,99).
Days needed for valid measurement	- 7-day monitoring periods traditionally used because they provide interclass correlations of >80% in most populations (22,198). - Shorter monitoring periods (4 or 5 days) have been suggested for children who might have less day-to-day variability in activity (200,201). - Data should include both week and weekend days (202) although toddlers possibly have less variation between the two (9,96).
Outcomes (22)	- Activity count-based measures: total counts per day, average counts - Energy expenditure-based measures: Kcal per day, MET-hours per day, Kcal per monitored hour, MET-minutes per monitored hour - Intensity-based measures: hours per day or % of wear-time in sedentary/light/moderate/vigorous activity - Posture-based measures: hours per day or % of wear-time in lying/sitting/ standing/stepping - Steps per day or steps per monitored hour

MET, metabolic equivalent; MVPA, moderate-to-vigorous physical activity; SD standard deviation

2.3.6 Value calibration, validation and feasibility of accelerometers

The output that accelerometers produce are accelerometer counts, which are arbitrary and depend on the specifications of the accelerometer model (18,203). Therefore, to give biological or behavioural meaning to these accelerometer counts, they should be converted to other constructs in calibration studies (18,203-205). This type of calibration is called *value calibration* (203,205). Another type of calibration studies is *unit calibration*, which is done in order to assess inter-instrument reliability of the devices (203,205).

The accelerometer monitors typically undergo unit calibration at the factory, and the new, microelectromechanical monitors do not necessarily need the end users to perform unit calibration (203). According to the manufacturers, the factory calibration is enough for the lifetime of the monitors, but the manufacturers rarely describe the actual calibration procedures (203,205). Therefore, some have recommended that the researchers as end users should perform unit calibration check e.g. with mechanical shakers using different accelerations and frequencies (203). Another method to test inter-instrument validity would be to ask study participants to wear two accelerometers simultaneously and then compare the output of the two monitors (205).

Value calibration is a validity issue and thus others refer to value calibration as validity research (205) whereas others separate value calibration and validation (164,203). In practice, value calibration and validation are often done within one study, where the accelerometer counts are first calibrated in one sample and then cross-validated using another sample (203).

Value calibration of accelerometer counts can be done in order to provide point estimates of energy expenditure or to establish cut points corresponding to certain activity intensity levels (203,204). Validation should be done against the most valid measurement method, i.e. gold standard (24,38,95,138). Although currently there is no consensus over gold standard method for measuring all aspects of physical activity (95,143,146,205), validation against indirect calorimetry, room calorimetry, doubly labelled water or direct observation has been recommended (24,203,206). The criterion method should be chosen in relation to the component of physical activity that is of interest (203,204,207). For example, if activity will be assessed to obtain estimation of time spent in different activity intensities, then direct observation or calorimetry could be the criterion measurement, whereas if total energy expenditure over several days is of interest, doubly labelled water could be used (207).

Table 8. ActiGraph calibration and validation studies for pre-schoolers and toddlers

Study	Methods for defining cut points	Defined count cut points	Methods for cross-validation	Cross-validation
Costa et al. 2014 (208)	ActiGraph GT3X+ against CARS observation in free play in 18 children aged 2.0 to 3.9 years	Counts/5s: - Sedentary ≤5 (vertical axis), ≤ 96.12 (VM) - MVPA ≥165 (vertical axis), ≥361.94 (VM)	In an independent sample of 20 children aged 2.0 to 3.6 years against CARS observation in free play	- Sedentary: sensitivity 85.4% for vertical axis, 87.6% for VM, specificity 87.3% for vertical axis, 88.4% for VM - MVPA: Sensitivity 83.6% for vertical axis, 82.2% for VM, specificity 84.2% for vertical axis, 83.1% for VM
Johansson et al. 2015 (209)	Actigraph GT3X+ against CARS observation in free play and structured activities in 26 children, mean age 26 (SD 6.0) months	Counts/5 s for wrist position: - Sedentary ≤89 (y-axis), ≤221 (VM) - Low intensity 90-439 (y-axis), 222-729 (VM) - High intensity ≥440 (y-axis), ≥730 (VM)	In an independent sample of 12 children, mean age 25 (SD 5.6) months against CARS observation in free play and structured activities	- Sedentary: Spearman rank correlation 0.91 (y-axis), 0.91 (VM) - Low intensity: Spearman rank correlation 0.89 (y-axis), 0.88 (VM) - High intensity: Spearman rank correlation 0.77 (y-axis), 0.69 (VM)
Oftedal et al. 2014 (210)	ActiGraph GT1M, GT3X and GT3X+ against computerised direct observation software Behavioral Evaluation Strategy and Taxonomy in 18 children aged 18-36 months	Sedentary counts/5s: - vertical axis <2 - VM <40	In an independent sample of 10 children with the same observation method	- Vertical axis: sensitivity 76%, specificity 93% - VM: sensitivity 82%, specificity 83%

Pate et al. 2006 (211)	MTI ActiGraph 7164 against oxygen consumption in 30 children aged 3 to 5 years (mean 4.4, SD 0.8) in structured activities using random-coefficient models	Counts 15s: - MVPA > 420 VPA > 842	In the same sample against oxygen consumption in unstructured activities	- MVPA: Sensitivity 96.6%, specificity 86.2% VPA sensitivity 65.5%, specificity 95.4%
Reilly et al. 2004 (212)	MTI ActiGraph against CPAF observation in 30 children 3 to 4 years (mean 3.7, SD 0.5) using ROC curve analysis	Sedentary: < 1100 counts /min	In an independent sample of 52 children, mean age 3.5 years (SD 0.5) against CPAF observation	Mean sensitivity 83% and mean specificity 82%
Sirard et al. 2005 (106)	MTI ActiGraph 7164 in structured activities in 16 children from 3 to 5 years (5 children 3-year-old) using ROC curve analysis	For 3-year-olds counts/15 s: - Sedentary 0-301 - Light: 302-614 - Moderate: 615-1230 - Vigorous ≥ 1231	In an independent sample of 281 children aged 3 to 5 years against CARS observation	Pearson correlation coefficients between accelerometer output and observed activity: sedentary 0.70, light 0.59, moderate 0.50, vigorous 0.61, MVPA 0.46
Trost et al. 2012 (105)	ActiGraph GT1M against CARS observation in free play in 22 children, mean age 2.1 years (SD 0.4), using ROC curve analysis	Counts /15 s: - Sedentary 0-48 - LPA 49-418 - MVPA >418	In an independent sample of 18 children, mean age 2.3 years (SD 0.4) against CARS observation in free play	Differences between observed and ActiGraph-measured activity: sedentary -7.6 min (95% limit of agreement -17.6 to 2.3, p<0.001), light 7.2 min (-2.0 to 16.3, p<0.0001), MVPA 0.5 min (-2.6 to 3.5, p=0.21)

CARS, Children's Activity Rating Scale; CPAF, Children's Physical Activity Form; LPA, light physical activity; MVPA, moderate-to-vigorous physical activity; ROC, receiver operating characteristics; SD, standard deviation; VM, vector magnitude; VPA, vigorous physical activity

The first calibration studies used general linear regression to plot accelerometer counts against energy expenditure and find the line of best fit (203,204). However, as relationship between accelerometer counts and energy expenditure is not always linear, other statistical methods have been suggested (204,205). These methods include two-regression equation, pattern recognition, receiver operating characteristics (ROC) curves and mixed models (18,203,204)

At the beginning of this PhD study, there were no calibration or validation studies of accelerometers for assessing physical activity of children less than three years of age (9). However, some value calibration and validation studies had been reported among pre-schoolers and those that used ActiGraph accelerometer are listed in Table 8. During the past three years, three value calibration and validation studies have been reported among healthy toddlers aged 2 to 3 years; in US (105) in UK (208) and in Sweden (209). In addition, one study in Australia validated the devices both in typically developing toddlers and toddlers with cerebral palsy (210). These studies are included in Table 8. The count cut points obtained in different methods have considerable variation. This complicates the comparison of results from different studies, because the use of different cut points results in discrepancies in estimates of physical activity (99,164,213,214).

After the onset of this PhD study, some studies have reported the feasibility and validity of accelerometer measurements among toddlers. Apart from the above-mentioned three value calibration and validation studies (105,209,210), one study assessed the feasibility and validity of ActiGraph accelerometer measurement among toddlers aged 12 to 30 months in Belgium (99). In that study, 64% of the children met the inclusion criteria of having enough wear-time during minimum of three days and the accelerometer counts were significantly and positively associated with observed activity levels (99). One study used focus group discussions to assess feasibility and acceptability of three accelerometers among mothers of 2- to 3-year-old children from multiethnic background in UK (215). The ActiGraph GT3X+ monitor was well accepted among the mothers to be worn by their children but the other two devices, Actiheart and the activPAL3 raised concerns regarding to their positioning on the body and size (215).

2.4 Interrelationship between physical activity and undernutrition in children

2.4.1 Definition and epidemiology of undernutrition

Malnutrition encompasses undernutrition and overweight, which are both significant global problems (1). Childhood undernutrition includes a wide array of conditions such as chronic undernutrition, acute undernutrition and deficiencies of essential vitamins and minerals (1,2,216). Young children are among the groups most at risk of undernutrition (2). The most crucial vitamins and minerals for children in regards to risk of undernutrition are iron, vitamin A, zinc and iodine (1,2,217-219). Chronic undernutrition is commonly reflected by growth stunting [low length-for-age z-scores (LAZ) or height-for-age z-scores (HAZ)] or underweight (low weight-for-age z-scores, WAZ), whereas wasting [low weight-for-length (WLZ) or weight-for-height z-scores (WHZ)] is often an indication of acute undernutrition (216).

The number of children affected globally by stunting, underweight and wasting has considerably decreased from 1990 to 2011 (Figure 3). The biggest numbers of undernourished children are in Asia, especially South-Eastern Asia (1,220). The highest prevalence of underweight (19%) and wasting (10%) are also in Asia whereas the highest prevalence of stunting (36%) can be found from Africa and Oceania (1,220). The global prevalence of different forms of undernutrition has been decreasing during the past decades (Figure 3), but the decreases have not been equally spread across different areas. The reductions in prevalence of both stunting and underweight between 1990 and 2011 were highest in Asia and Latin America and the Caribbean and lowest in sub-Saharan Africa and Oceania (220,221).

The country-level estimates do not give a full picture of the situation within countries, which can vary according to the inequalities in socioeconomic situation. In almost all low- and middle-income countries, children in urban areas are on average taller and heavier than their counterparts in rural areas (222). Furthermore, some data show that the stunting prevalence within the country can be on average 2.5 times higher in the poorest fifth than in the richest fifth (1). The socioeconomic inequalities in undernutrition seem to show high degree of persistence over time as the differences have not changed considerably between 1990 and 2011 (223).

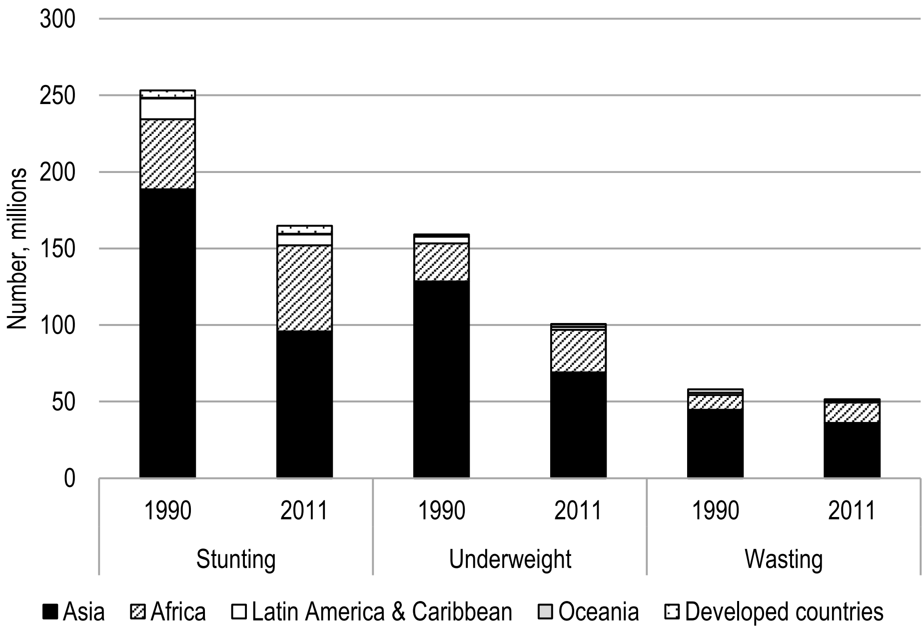


Figure 3. Estimated number of stunted (HAZ < -2), underweight (WAZ < -2) and wasted (WHZ < -2) children under five years globally in 1990 and 2011. Modified from UNICEF 2012 (220)

2.4.2 Health and developmental consequences of childhood undernutrition

Undernutrition causes significant mortality and morbidity. UNICEF estimated that almost half of the 6.3 million deaths of children under 5 years in 2013 were attributable to undernutrition (224). According to the Global Burden of Disease Study, 1.4 million deaths in 2010 were attributable to child and maternal undernutrition, a significant decrease from 3.5 million in 1990 (217). The differences in the estimates reflect the poor availability of data on causes of deaths and discrepancies in the interpretation of epidemiological evidence (217).

Undernutrition and infectious diseases have a bidirectional relationship (225). A vicious circle between undernutrition and infections, whereby poor nutrition increases the risk of contracting infections and infections impair nutritional status, is well described (2,226,227). Undernutrition, especially deficiencies in energy, protein, vitamin A, iron, magnesium, zinc and vitamin D, interfere with immune functions and thus increase the susceptibility to infections (2,227). Some of the infectious diseases that commonly have detrimental effect on nutritional status are

AIDS, tuberculosis, diarrhoea and intestinal parasites (227). One common subclinical disorder in low-income settings is environmental enteropathy, which can cause nutrient malabsorption and increased intestinal permeability (225,228-230). Environmental enteropathy is thought to be a near-continuous state of immune system activation in the gut caused by chronic ingestion of harmful micro-organisms (225,228-230).

Many nutrients, e.g. protein, fatty acids, iron, iodine, zinc, choline and B-vitamins are necessary for brain development, and thus poor nutrition during pregnancy and in infancy has the potential to hamper cognitive, motor and socio-emotional development (231). Whether poor nutrition will affect development is influenced by several other factors, such as stimulation from the environment, timing and degree of nutrient deficiency and the possibility of recovery (231). Several observational and case-control studies have shown associations between severe malnutrition or stunting and poor cognitive and motor development in early childhood (14,232). Randomised trials of food supplementation, which can offer stronger evidence of causal effects, have also indicated that nutrient supplementation may have a positive effect on motor development of infants and cognitive development of pre-schoolers and school-aged children (231,233).

Childhood undernutrition also has considerable long-term consequences. Undernutrition in childhood, especially stunting, has been associated with shorter adult height, poorer cognitive function, lower education levels, reduced economic productivity and lower offspring birth weight (3,231,234,235). Stunting in early life may also be associated with poorer mental health status in adolescence (1). Furthermore, growth failure in early life is a risk factor for cardiovascular disease in later life (230). On the other hand, faster linear growth in the first two years of life has been associated with higher adult body-mass index, increased adult height and more years of schooling along with little association with adult cardiovascular risk factors (5). The association between stunting and poorer long-term outcomes can come in two ways: 1) stunting can be the direct cause of the poorer outcomes or 2) stunting can be a key marker of the underlying processes that lead to the adverse outcomes (235).

2.4.3 Undernutrition and physical activity

As a response to lowered energy intake, as is the case in acute undernutrition, the human body takes series of physiological and behavioural changes (236,237). In infants and children, the changes include restriction of growth, changes in body composition (loss of muscle mass and fat but sparing of brain), reduction in absolute basal metabolic rate and behavioural reduction of physical activity (236,237). Reducing energy expenditure in motor activity is thus one strategy for undernourished children to maintain their energy balance (237,238).

Several studies have shown that undernourished children are indeed less active than better nourished children. Early studies in Uganda (239), India (240), Nepal (241) and Jamaica (242,243) showed that undernourished infants and toddlers were less physically active, as measured by observation, than well-nourished children. Similar results have been obtained from more recent studies regarding chronic and acute undernutrition. Stunting was associated with lower observed physical activity among infants in Mexico (244) and Zanzibar (245). Ethiopian children with severe, acute malnutrition expressed very low accelerometer-measured activity counts when admitted for treatment, with little difference in activity levels between night and day (13). A study in India reported lower observed activity grades in wasted versus non-wasted children (246).

Certain micronutrient deficiencies have also been associated with low activity levels. The most studied micronutrient deficiency in regards to activity is iron deficiency or iron deficiency anaemia, but the results are equivocal. Some studies have shown reduced physical activity among infants with iron deficiency (244,245,247,248) whereas one study found increased physical activity among infants with iron deficiency anaemia as compared to non-anaemic controls (249).

Undernutrition, physical activity and development interact in several ways. Pollit and colleagues (1993) suggest a theory by which the relationship between malnutrition and delayed cognitive and behavioural development is mediated by the effects of malnutrition on body size, motor maturation and physical activity (238). According to the theory undernourished children 1) have small body size which induces social responses from other people that are generally reserved for children of younger age, 2) have slow motor maturation that delays acquisition of cognitive skills and social behaviours and 3) have low level of motor activity that limits their exploratory behaviour (238). Another way to link undernutrition with poor development is the *functional isolation* hypothesis. According to this theory, the behaviour of undernourished children, i.e. reduced activity, exploration and apathy, results them to have less interaction with their environment and this in turn may lead to poor development (14,248,250). Moreover, in response to the undernourished children's behaviour, caregivers may also offer less stimulation which again hampers development (14,248).

Another aspect of the interaction between undernutrition, physical activity and growth was seen in the study of Torun and colleagues with 2 to 4 year old children in Guatemala (251). They found that children who were stimulated to participate in physical activity while being treated for protein-energy malnutrition gained more height and lean body mass than children who were not stimulated to be active (251). The increase in height implies that inactivity that is related to acute undernutrition may in fact be contributing to stunting (251).

2.4.4 Effect of nutrient supplementation on physical activity of undernourished children

One strategy to improve nutritional status of infants is through enhanced complementary feeding (6). According to the recommendations, period of complementary feeding means the time of introducing other foods in addition to breast-feeding between 6 and 23 months of age (6,252,253). In addition to the overall nutrient density of the complementary foods, the critical nutrients at this stage are iron and zinc (252). Complementary feeding interventions to improve nutritional status of infants include nutrition education, provision of complementary foods or providing supplements of vitamin A, iron, zinc or multiple micronutrients (6,253).

Although studies testing nutrition interventions in prevention of undernutrition have mostly targeted growth as their main outcome, some of them have also assessed the effect of the nutrition intervention on physical activity (Table 9). Several of them reported positive effects of nutrition intervention on physical activity (254-257), one no effect (243) and one reported mixed results (258). All of the studies used observation as the measure of activity.

The interventions used in the studies varied. Two of the studies demonstrating a positive effect of supplementation on activity used zinc supplement (255,256) and two used supplement including milk and multiple micronutrients (254,257). However, of the two studies testing milk supplement and resulting in positive findings, the study of Aburto and colleagues did not find effect with the milk supplement but only with multiple micronutrient syrup or powder (257). Furthermore, the study of Harahap and colleagues (254) in Indonesia was a sub-sample of the study of Jahari and colleagues (258) and included only children with iron-deficiency anaemia. The positive effect of condensed milk and micronutrient tablet on physical activity in the Indonesian study was present only with the subsets

Table 9. Nutrition interventions measuring physical activity

Study	Participants	Intervention groups	Method of physical activity measurement	Results
Aburto et al. 2010, Mexico (257)	4 to 12 months-old beneficiaries of Mexican government's conditional cash transfer program, n=187	4-month supplementation, randomised at community level 1) Whole-milk based, fortified supplement 2) Multiple micronutrients, syrup or powder 3) Children at enrolment as comparison group	Direct, video-recorded observation for 12 min	- Odds for being in high-activity cluster higher in the micronutrient group (OR 2.63, 95%CI 1.14 to 6.07) than in the control group - No difference for the milk-based supplement (OR 2.20, 95%CI 0.82 to 5.92) compared to the control
Bentley et al. 1997, Guatemala (256)	6 to 9 months-old children, n=85	7-month supplementation, randomised 1) 4 mL supplement with 10 mg zinc sulphate 2) 4 mL placebo supplement Both delivered home daily	Time sampling observation at 10 min intervals over 12 hours, at baseline (mean age 6.9 months) and follow-ups at 10.1 and 14.5 months of age	- No differences at follow-up 1 - At follow-up 2, zinc-supplemented infants were more frequently observed sitting up, compared with lying down, and were playing during 4.18 (P <0.04) more observations than unsupplemented infants.
Harahap et al. 2000, Indonesia (254)[1]	12 and 18 month-old children from day care centres, anaemic and non-anaemic, n=36	12-month supplementation, 6 days a week, randomised at day care centre level 1) Condensed milk + micronutrient tablet 2) Skimmed milk + micronutrient tablet 3) Skimmed milk + placebo tablet.	Direct observation, 2 hours at day care centre and 2 hours at home, every 2 months	During 6 months of intervention, anaemic children (who received interventions 1 or 2) became more active than the non-anaemic children (receiving intervention 3)

Jahari et al. 2000, Indonesia (258)[1]	12 and 18 month-old children from day care centres, n=136	Same as above in Harahap 2000	Same as above in Harahap 2000	- In the 12-month-old cohort, supplement groups 1 and 2 increased their motor activity scores more than group 3. - No significant treatment effects in the 18-month-old cohort.
Meeks Gardner et al. 1995, Jamaica (243)	9 to 24 month-old stunted children, n=78	24 month supplementation, randomised 1) Milk-based supplement 2) Milk-based supplement + psychosocial stimulation 3) Control	Direct observation for 2x4 hours at enrolment and 2x3 hours after 6 months of supplementation	Activity of the stunted children increased over time but it was not associated with supplementation
Sazawal et al. 1996, India (255)	12 to 23 month-old children, diarrhoea patients from a dispensary, n=93	6 month supplementation with 1) 5 mL of multiple micronutrient liquid 2) 5 mL of multiple micronutrient liquid with zinc gluconate (10 mg of elemental zinc) delivered home daily	Time sampling observation at 10 min intervals over 2x5 hours after varied days of supplementation. Coded with CARS and estimated energy cost.	- Children in the zinc group spent 72% more time in high-movement intensity than children in the control group (8.1% vs 4.7%, P <0.005). - Activity rating by CARS was 12% higher (P <0.01) and energy expenditure score was 8.3% higher (P <0.02) in the zinc group

[1] From the same study. Methods reported at Pollit 2000 (259)

CARS, Children's Activity Rating Score; CI, confidence interval of the anaemic children and the 12-month-old cohort, but not in the 18-month-old cohort (254,258). Meeks Gardner and colleagues found that while the activity of stunted children increased along with their age, the increase was not related to the milk-based supplement (243).

The studies also used different durations of the interventions. The two studies using zinc supplement measured physical activity on several time points during the supplementation (255,256). The study of Bentley and colleagues did not find effect on activity at the first follow-up, which was after three months of supplementation, but only at second follow-up, after seven months of supplementation (256). Sazawal and colleagues measured activity after varying duration of intervention, but they reported that at the time of measurement 71% of the children had received the zinc supplementation for minimum of 120 days (255). The other studies indicating positive effect of supplementation on activity measured activity after four (257) or six (254) months, whereas the study reporting no effect measured activity after 6 months of supplementation (243).

In addition to the studies testing supplementation either on prevention of undernutrition or treatment of chronic undernutrition, one study has measured physical activity before and after treatment of severe acute malnutrition (13). In the study of Faurholt-Jepsen and colleagues, 13 Ethiopian children with mean age of 31 months diagnosed with severe acute malnutrition wore an accelerometer for four days after admission to a nutrition rehabilitation unit and after about 10 days of rehabilitation (13). The wrist-measured activity was 2.5 times greater at follow-up than at baseline ($p = 0.003$), whereas hip-measured activity was significantly greater at follow-up only when night time activity was excluded from the data (13).

2.5 Justification for the present study

This study was designed to fill in some of the gaps in research regarding the use of accelerometers in toddlers, effects of LNS intervention on children's physical activity and examination of parental perspectives towards physical activity in a low-income country context.

As the literature review shows, accelerometers have not been widely used in toddlers aged 1 to 3 years. One of the reasons for their scant use is the lack of validation studies in this age group until very recently (9,260). Only three studies from very recent years have assessed validity and feasibility of accelerometers in this age group (99,105,209). We conducted studies I and II to test the feasibility of accelerometer measurement by assessing the accelerometer wear-time of 16 to 18 month-old toddlers and by recording their parents' experiences of the measurement. In study I we also compared the accelerometer counts to observed physical activity to test the validity of the method.

Some studies have measured the effect of nutrient supplementation on physical activity of children in areas of high prevalence of undernutrition, but they have not used accelerometers in assessing physical activity. Accelerometer measurements offer more valid information on the relationship of physical activity and health (193). As an intervention to prevent undernutrition in children, LNS are currently widely studied. However, no studies so far have assessed the possible effect of LNS intervention on physical activity. Furthermore, there clearly is paucity of information on physical activity levels of children in sub-Saharan Africa, especially measured by objective methods instead of self-reports. In study II we tested the effect of one-year LNS intervention on accelerometer-measured physical activity of Malawian toddlers in a randomised, controlled trial.

Parents' perceptions of physical activity are associated with the activity level of young children who live under parental influence (25,26). Although parental perceptions of children's physical activity have recently been studied, the studies originate from high-income countries and information from low-income countries and sub-Saharan Africa is lacking. The studies from high-income countries show that parental views on facilitators and barriers of children's physical activity are context-specific, especially in relation to interpersonal, cultural and environment-related factors. Thus the results of these studies can not be translated to sub-Saharan African settings. In study III we interviewed Malawian parents and key informants on their perceptions of children's physical activity.

Overall, this study intends to utilize both quantitative and qualitative methods. Combining quantitative and qualitative approaches can give a rich view on peoples' behaviour and the belief systems that affect those behaviours (261).

3 Aims of the study

This study aimed to obtain a multifaceted view on measurement and determinants of physical activity of young children living in food insecure area in semi-rural sub-Saharan Africa. Physical activity was investigated trough accelerometers as a measurement method, nutrient supplementation as a determinant and parental perceptions as the cultural context where habitual physical activity of the children takes place.

The specifics aims were:

1. To assess the feasibility of ActiGraph accelerometer in measuring physical activity of toddlers.

2. To assess the validity of ActiGraph accelerometer in quantifying physical activity of toddlers.

3. To test the hypothesis that semi-rural Malawian children who receive 10, 20, or 40 g/day of micronutrient fortified lipid-based nutrient supplement (LNS) from 6 to 18 months of age would have higher mean accelerometer counts at the end of the intervention than children who have not received dietary intervention.

4. To investigate how parents of young Malawian children conceptualise physical activity in childhood, situate it in child development and understand its facilitators.

4 Materials and Methods

4.1 Approach to the study and the author's role

Data from three different studies were used to meet the four aims of the PhD study (Figure 4). The data collection of Study I was carried out in Lungwena between October and December, 2010. In study I, 56 children were wearing the ActiGraph GT3X accelerometer for one week and visited daily by research assistants. The author designed the study, planned the data collection methods, trained the research assistants, was present at the research site for the whole duration of the data collection and coded all the video material that was used in the analyses.

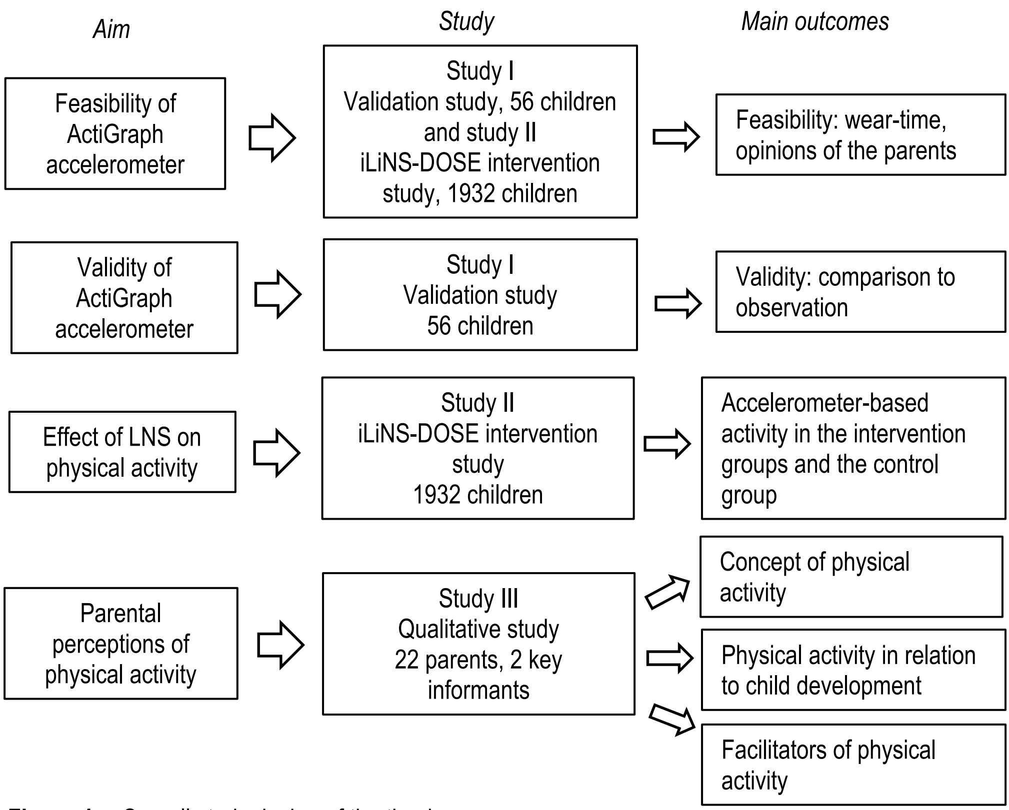


Figure 4. Overall study design of the thesis

Study II was a sub-study of a larger intervention trial, iLiNS-DOSE, where 1932 children received LNS from the age of 6 months to the age of 18 months. ILiNS-DOSE data collection team delivered the intervention and organized the interim visits. Activity was assessed with one-week ActiGraph accelerometer measurement at the end of the intervention period, between December 2010 and July 2012. The author planned the accelerometer assessment and trained the data monitor and the research assistants. She also was present at the research site at the onset of the data collection and three times subsequently, about a month at a time. The everyday data collection was organized by the data monitor. While not at the research site, the author was overseeing the data collection remotely.

Study III was a qualitative study where 22 parents of young children and two key informants participated either in an in-depth interview or a focus group discussion. The data collection was carried out between October 2010 and February 2013. The author conducted interviews for eight of the parents and the two key informants and facilitated the focus group discussion, all in English. A research assistant trained by me conducted the remaining interviews for eight of the parents in one of the local languages, Chi-Chewa. The author transcribed the English interviews and the research assistant the Chi-Chewa interviews.

The author cleaned all the data for the study I and activity data for the study II and conducted the analyses of all the studies. She also drafted all the three manuscripts with a help of the comments from the co-authors and was the first author in them.

4.2 Study setting

All three studies took place in Mangochi District, Southern Malawi. Malawi is located in southeast Africa and covers 118 484 km^2 of area, of which 94 080 km^2 is land (see Figure 5). The main geographical features are Lake Malawi on the eastern boundary of the country and the Rift Valley, which runs through the country from north to south (262). The population of Malawi was estimated at 15.9 million in 2012 with estimated 45% of the population being under 15 years of age (263). In 2012, the gross-national income per capita was about 730 international dollars and only 16% of people lived in urban areas (263).

Malawi has high infant mortality and high prevalence of chronic childhood undernutrition but the health situation is improving. Under-5 mortality rate has declined from 244 in 1990 to 71 in 2010 and infant mortality rate from 142 to 42 during the same time period (263). Percentage of children under age of five who were stunted (HAZ < -2 SD) decreased slightly from 53% in 2004 to 47% in 2010 while the % of children who were wasted (WHZ < -2 SD) was low and remained almost the same, 6% in 2004 and 4% in 2010 (262). Life expectancy at birth has also improved, from 45 years in 1990 to 59 years in 2012 (263).

Mangochi district lies in the northern corner of Southern region of Malawi. It had an estimated population of 797 000 in 2008 (264). The studies included in this thesis were done in the catchment areas of Mangochi district hospital, Namwera health centre and Lungwena health centre (see Figure 5). Mangochi town is semi-urban whereas Lungwena and Namwera are rural areas. The main languages spoken in the area are Chi-Yao and the national language, Chi-Chewa, with English also widely spoken among the educated population.

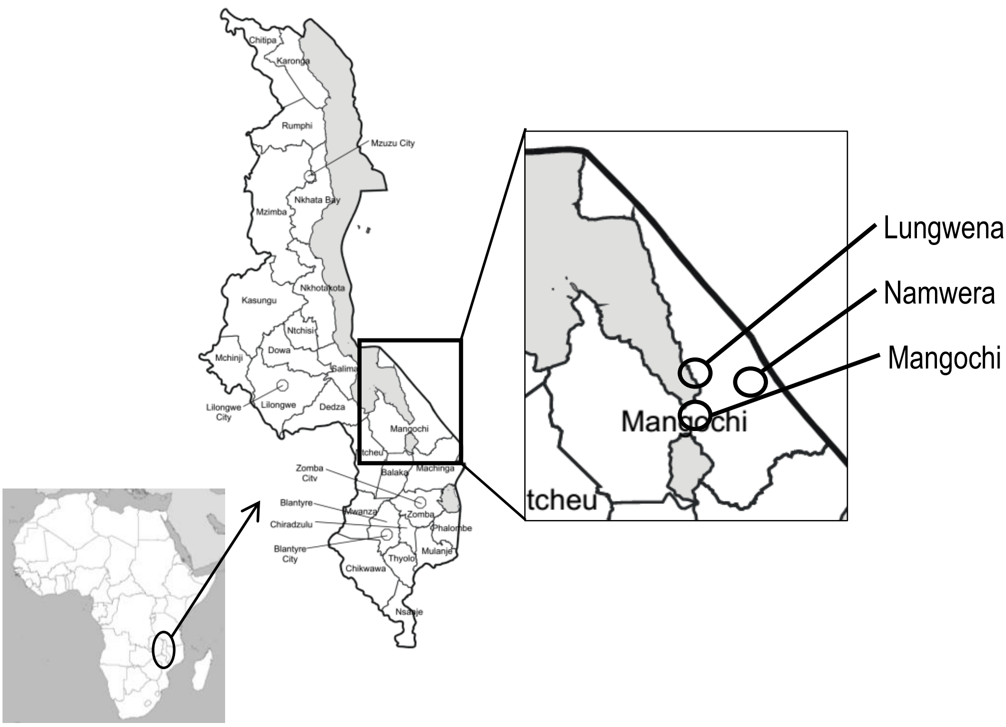


Figure 5. Map of Malawi with study sites marked. Modified from National Statistical office of Malawi, 2011 (264). Map of Africa from www.mapsopensource.com.

4.3 Participants

Three sets of participants were recruited in to the studies (Table 10). Participants of studies I and II were 16 to 18 months old children and participants of study III were parents of young children. In study I, participants were identified through discussions with village heads and community surveys in Lungwena area. Participants for study II were those who attended iLiNS-DOSE intervention trial. They were initially identified through community screening and later recruited to this sub-study if they attended the second last visit of the intervention period at the age of 18 months, still resided in the study area and if their guardians gave informed consent for this sub-study. Participants for study III were recruited by convenience sampling, aiming at recruiting interviewees with different gender, education background and area of residence.

Table 10. Descriptions of three groups of participants of the studies included into the thesis

	Study I	Study II	Study III
Area	Lungwena	Mangochi and Namwera	Mangochi, Lungwena and Namwera
Number of participants	56	1932	24
Recruitment	Through community surveys	First through community surveys, to this sub-study by including all iLiNS-DOSE participants who came to the visit	Convenience sampling
Enrolment age	16 to 18 months	18 months	Adults
Key exclusion criteria	Chronic illness, WHZ < -2 SD	No consent for the activity sub-study, did not come to the visit within 30 days of planned	Not a parent or a key informant

4.4 Interventions in study II

Only study II included interventions to the participants. A data monitor randomised participants into study groups by presenting them a set of opaque envelopes that included the randomisation slips. The research group had made the slips prior to the participant recruitment based on a randomisation list created by a statistician who was not involved in the data collection. Guardian of the participant then chose one of the envelopes. Blocks of 24 were used in the randomisation so that the participants were evenly spread into the groups throughout the recruitment period.

The study had six arms: one control group and five intervention groups. The participants in the intervention groups received one of the five interventions daily from 6 to 18 months of age while the participants in the control group received a delayed intervention of 71 g of fortified maize/soy flour daily from 18 to 30 months of age. The intervention groups received either 10 g of milk-containing lipid-based nutrient supplement (LNS), 20 g of milk-containing LNS, 20 g of non-milk-containing LNS, 40 g of milk-containing LNS or 40 g of non-milk-containing LNS daily. LNSs are products that contain vegetable oil, peanut butter, milk powder, sugar, vitamins and minerals in a form that is acceptable for children, has long shelf life and is easy to produce and consume (265-267). Large-quantity LNS are widely used in treatment of severe acute malnutrition (15,268) and the use of small-quantity LNS, as in the current study, in promotion of linear growth and improvement of micronutrient status is currently under investigation (267).

LNS was produced by Nutriset S.A.S. (Malaunay, France) and packed in 140 g plastic cups. The guardians were instructed to offer their infants either 2, 4 or 8 spoonfuls (10 to 40 g) of LNS, mixed in small amount of complementary porridge and served in 2-4 daily doses. All doses of LNS were fortified with similar amount of 22 micro- and macronutrients, approximately one recommended daily allowance of each (see Supplementary Table 1 of article 2 for detailed information of the contents of the supplements). Iron concentration, however, was moderate (6 mg), to protect from possible side effects of long-term iron supplementation in malaria-endemic area (269). Energy, protein and fat content, including essential fatty acids, depended on the dose and milk content of the LNS. Energy content for 10 g, 20 g and 40 g doses were 55, 117 and 241 kcal, respectively.

4.5 Outcome measures

4.5.1 Follow-up

In study I, the participants were followed up for one week during which they were wearing the accelerometer. Research assistants visited them every day to check if they were wearing the device and whether it was attached correctly on the right hip.

In study II, the participants were followed up by two-weekly home visits and six-monthly clinic visits during the one-year intervention period. At the end of the intervention period they wore the accelerometers for one week, during which they still received the intervention. Background variables for the activity sub-study were derived from the enrolment visit at 6 months of age and from the two last clinic visits, 52 and 53 weeks after the enrolment. The accelerometer measurement was conducted only once, at the end of the trial, between the two last visits.

Study III did not have a follow-up period. The participants either were interviewed once or they attended the focus group discussion once.

4.5.2 Accelerometer measurement

Physical activity was measured in studies I and II. Research assistants or research nurses gave the devices to the participants and instructed the guardians how to secure the device on the child's right hip using elastic belt. They also instructed the guardians that the child should wear the device throughout day and night. The measurement period was one week but 63 of the children in study II were asked to wear the device for a second week as the data from the first showed low compliance with the measurement (i.e. less than four days with minimum of 6 hours of data). Furthermore, in study II, some participants did not come to the study clinic for returning the device after seven days, resulting them to have a longer measurement period.

The epoch length used in these studies was 15 s. Although epoch lengths less than 60 s are generally recommended for children, there is no consensus on the best epoch length (9,18). Several authors have used (98,99,104,105) and recommended (9,152,192) 15 s epochs for toddlers and pre-schoolers. As the memory size of the devices was not a limiting factor in the one-week measurement in studies I and II (Table 11), we chose to use 15 s epochs.

The two accelerometer models used in the studies were ActiGraph GT3X (ActiGraph LLC, Pensacola, USA) in study I and ActiGraph GT3X+ (ActiGraph LLC, Pensacola, USA) in study II (Table 11). Both of the models had a tri-axial capacitive accelerometer (171). The analog signals were digitalized by a twelve-bit analog-to-digital converter at a rate of 30 Hertz in GT3X and using user-specified rate of 30 Hertz in GT3X+. After that, the signal passed through a digital filter that limited the bandwidth of 0.25 to 2.5 Hertz, which was determined by the manufacturer to detect normal human motion (171).

Table 11. ActiGraph accelerometers and measurement procedures used in studies I and II

	Study I	Study II
Model of ActiGraph	GT3X	GT3X+
Number of units used	10	35
Dimensions, cm	3.8 x 3.7 x 1.8	4.6 x 3.3 x 1.5
Weight, g	27	19
Accelerometer	ADXL335 (Analog Devices, Norwood, Ma, USA)	KXSC7 (Kionix Inc, Ithaca, NY, USA)
Sampling rate	30 Hertz	30 to 100 Hertz[1]
Digital filtering	0.25 to 2.5 Hertz	0.25 to 2.5 Hertz
Measurement range, G	0.05 to 2.5	-6 to +6
Memory size (number of recording days with 1 s epoch, 30 Hz rate)	16 MB (21 days)[2]	256 MB (21 days)[2]
Starting place of measurement	At the study clinic or at home	At the study clinic
Length of measurement	7 days	7 to 20 days
Attachment of the device	Right hip, elastic belt	Right hip, elastic belt
Home visits during the measurement	1/day	0-3/week

1 30 Hertz frequency was pre-specified when the units were initialised

2 GT3X+ records raw data which takes considerably more memory space than the epoch data in GT3X.

The two accelerometer models have small technical differences, as presented in Table 11, but the resulting activity counts and activity classification have shown very good agreement (175,270). One of the practical differences is that GT3X+ allows saving of the raw data which later on can be processed into the chosen epochs whereas when using GT3X, the epoch length must be selected before the initiation of data collection. Furthermore, the GT3X is an older model and not waterproof, so the parents in study I were instructed to remove the device for water-based activities such as bathing.

The ActiGraph devices were initialized and the data downloaded using a computer with ActiLife software (ActiGraph LLC, Pensacola, FL, USA). The author initialised the devices and downloaded the data in study I and a trained research monitor did the same in study II. In study II where newer GT3X+ models were used, the author later converted the raw data files into 15 second epochs using the same software. The author also monitored all the incoming data:

daily in study I and when the data were available from Malawi (about every two-three months) in study II.

The research assistants checked whether the child was wearing the device in the instructed way: snugly on the right hip. This was done by daily home visits in study I, and once at the end of the measurement period in study II (Table 11). In addition, subsection of the participants in study II were visited at home once, twice or three times during the measurement period to check the wearing of the device. At the end of the measurement, research assistants enquired the guardians' opinion of the measurement by completing a local-language (Chi-Chewa or Chi-Yao) questionnaire with them. The responses were recorded in four categories: "went well", "went mostly well", "had quite a lot of problems" and "was very problematic".

4.5.3 Activity observation by CPAF method

The research assistants video recorded the children twice during the activity measurement period in study I using a digital video camera (Canon FS-306, Canon Inc, Tokyo, Japan). The recordings, which were a minimum of 3 days apart and lasted for a minimum of 60 minutes, were carried out while the children were playing freely outdoors at their homes. The last 30 minutes of each recoding was used in coding of the activity observation. The clocks of the video camera were synchronized with the computer that was used for initialising the accelerometer. The accelerometers derived the time from the computer during initialisation.

The author coded activity observations using the CPAF method, which has earlier been validated against heart rate monitoring (156). A researcher experienced with the CPAF method (Ms Victoria Penpraze) taught the author how to employ the method prior to the actual onset of coding using video material that was not included in the analyses.

The CPAF categorizes activity into four levels: 1) stationary, no movement; 2) stationary, limb movement; 3) slow trunk movement and 4) rapid trunk movement (156). The method was originally designed for 60 second measurement intervals, but an interval of 15 s was used in this study. According to the method, the primary coder (the author) and the second coder (Ms Victoria Penpraze) ticked all the activity levels that were present during the 15 second period. The coders also ticked if the child was not visible or was carried or lifted by other people during the 15 second epoch. Only those epochs with only one activity present during the whole duration of the 15 second epoch and where the child was visible and not carried were included in the analyses. Carrying was excluded because it would result in the accelerometers recording movement that was not generated by the child, especially as in the area children's movements are very restricted when they are carried in the back in the traditional Malawian way, secured by a cloth (*chitenge*).

The total amount of epochs analysed was 8971 (2243 minutes), 121 to 151 epochs (30 to 38 minutes) per recording session. To assess inter-observer validity the second observer analysed 19% of the epochs, i.e. 1719 epochs. For clean epochs, inter-observer agreement was 60% (kappa 0.35). To assess intra-observer validity, the first observer coded 10% of the epochs (n = 932) and the second observer 100% of the epochs (n = 1719) for a second time. Intra-observer agreements were 83% (kappa 0.61) for the first observer and 92% (kappa 0.88) for the second observer.

4.5.4 Other outcome measures

In studies I and II, the participants came to the study clinics for eligibility assessment and in study II, they additionally came to the clinics when the accelerometer measurement was starting. During these visits trained study nurses checked the children's health status and recorded their sex. Research assistants obtained the children's date of birth from their health passports (personal booklets containing the child's health record), measured their weight to the nearest 10 g using electronic weighing scales (OBH Nordica 6201, OBH Nordica, Stockholm, Sweden in study I and SECA 735, Chasmors Ltd., London, UK in study II) and measured their height to the nearest 1 mm using a length board (Kiddimetre, Raven Equipment Ltd, Essex, UK in study I and Infantometer, Child Growth Foundation, London, UK in study II). Weight and length were measured in duplicate in study I and in triplicate in study II. LAZ and WLZ were calculated using the WHO 2006 Child Growth Standards (271).

In study I, the ability of the children to walk was assessed by the author while coding the videos and in study II, trained developmental assessment research assistants assessed the same during the end-of-measurement visit. The research assistants interviewed guardians at the enrolment visit to obtain information on maternal education and maternal age in study II. Trained research assistants also used a local-language questionnaire to obtain information on household food insecurity by Household Food Insecurity Access Scale (HFIAS) (272).

4.6 Statistical analysis

4.6.1 Accelerometer data reduction

We set the accelerometer epoch at 15 s in studies I and II (Table 12). The following data were excluded from the wear-time analysis in studies I and II and main outcome analysis in study II: 1) first and last day of measurement, 2) night time and 3) strings of 20 minutes or more of zeroes. After excluding these data we considered a day valid if it had minimum of ten hours of data in study I and minimum of six hours of data in study II. Ten hours for study I was chosen because the aim of the study was to assess how much the children would wear the device and this offered a more conservative estimate than less amount of time. Minimum of four days of valid data for a child was required for the analyses in both of the studies. Maximum wear-time was not defined i.e. we included all the collected data in the accelerometer analyses.

Table 12. Accelerometer data reduction in study I and study II.

	Study I	Study II
Epoch length	15 s	15 s
Data exclusion	1. First and last day of measurement 2. Night time (8 p.m. to 5 a.m.) 3. Strings of ≥ 20 minutes of 0 counts	1. First and last day of measurement 2. Night time (8 p.m. to 5 a.m.) 3. Strings of ≥ 20 minutes of 0 counts
Data needed for valid day	≥ 10 hours	≥ 6 hours
Days needed for valid measurement	≥ 4 days	≥ 4 days

In study II, the main outcome measure was mean vector magnitude counts/15 s. It was calculated by averaging mean counts/15 s of each day over all valid days for each of the participants. The secondary measures were mean vertical axis counts/15 s as well as % of time spend in MVPA by vector magnitude and the vertical axis. We used MVPA cut points of 208 counts/15 s for vector magnitude that was defined in study I, and 49 counts/15 s for the vertical axis (105) that has been used more widely.

4.6.2 Statistical analyses in study I and study II

The author carried out the statistical analyses with Stata software, versions 11.2 in study I and study II and version 12.1 in the thesis summary (StataCorp, College Station, TX, USA). We set the level of statistical significance at 0.05 for all other analyses except for the likelihood ratio test for effect modification in study II where we set it at 0.10.

In studies I and II, we calculated the proportion of participants who had minimum of four days of either six or ten hours of data with 95% confidence interval (CI), based on binomial distribution. In study I, we tested the hypothesis of a direct and positive association between the ActiGraph counts and observed activity with quantile regression, taking into account the cluster effect of multiple epochs for each participant. ROC curves with area under curve (ROC-AUC) and their 95% CIs were determined to examine the classification accuracy of accelerometer counts (205,273). We also used the ROC curves in the value calibration to determine the best cut point for separating MVPA from lighter activity. The cut points showing equal level of sensitivity and specificity were chosen and applied to the cross-validation sample of second video recordings to determine sensitivity and specificity. All the accelerometer analyses were carried out separately for vector magnitude and the vertical axis.

In study II, the statistical significance of differences in rate of loss to follow-up between groups was tested with Fisher's exact test. We used Student's t-test to test the hypothesis of physical activity being greater in the intervention groups than in the control group individually for each intervention group and outcome. We tested the interaction between the interventions and six pre-specified variables, namely LAZ at 6 months, WLZ at 6 months, sex, season of birth, maternal age, maternal education and HFIAS, with likelihood ratio test. As a secondary analysis, we constructed a regression model including the above mentioned six variables but not those that were found to be effect modifiers. As a sensitivity test for the latter analysis, we built two regression models: 1) inclusion of all six variables and 2) inclusion of only those variables that were associated with physical activity at $p<0.1$ level.

For study I, we set the sample size in regards to the wear-time analysis: at least 50 participants were chosen to get a level of precision of at least ±15% for estimating the prevalence of wearing the device for minimum of 4 days. For study II, the sample size was originally calculated according to the main objective of the iLiNS-DOSE trial: a sample size of 320 per group provided 90% power and 95%

confidence (one sided test) to discard the inferiority null hypothesis of change in LAZ of infants receiving 20 or 40 g/day of LNS without milk from 6 to 18 months of age not being lower than that of infants receiving a comparable intervention with milk-containing LNS. According to post hoc calculations, the acquired sample size of about 180/group provided this study with about 80% power to detect an effect size of 0.3 in continuous outcomes at 5% two-sided type I error rate.

4.7 Data management

The author converted the accelerometer epoch data into a .csv file in the ActiLife software and further into Stata data files. She also coded the CPAF analysis into an Excel file and converted it into a Stata file.

We collected all the other data in studies I and II on paper forms. In study I, data clerks entered the data into a database manually with Microsoft Access, version 2007 (Microsoft Corporation, Redmond, WA, USA). In study II, they entered data either manually with Microsoft Access, version 2007 and REDCap, version 4.14.4 (hosted at University of Malawi) or using Cardiff-Teleform system, version 10.5 (Digital Vision, Highland Park, IL, USA). The manual data entry was done as double entry. With the Cardiff-Teleform system, the data were entered once by scanning the paper files into the system. Data clerks then checked certain pre-specified values (such as participant number and date of the visit) and all suspicious values as prompted by the system. All the data were combined to MySQL database, version 5.1.48 (Oracle Corporation, Redwood Shores, CA, USA). We checked all the remaining suspicious and missing values against scanned paper forms, which were saved as pdf files.

4.8 Qualitative methods

We collected the data for study III with in-depth interviews (IDI) and a focus group discussion (FGD). The interviews were voice recorded. We used an interview guide that had mostly open-ended questions on background information of the respondents and their views on signs and facilitators of physical activity, good child development and expectations for their children’s future. Interviews were continued until saturation was reached.

We first transcribed the IDI's and the FGD and, in the case of interviews done in Chi-Chewa, translated them into English. Subsequently, the data were saved and organised in ATLAS.ti programme, version 6.2 (Atlas.ti GmbH, Berlin, Germany). The author conducted the data analysis by inductive approach using conventional qualitative content analysis (274,275). After reading through the IDIs and the FGD several times, she coded the emerging meaning units. After coding, the codes were grouped into categories and categories further into themes.

4.9 Ethical aspects

The studies included in this thesis conformed to the ethical guidelines of the 2008 World Medical Association's Declaration of Helsinki, which urges researchers to "*protect life, health, dignity, integrity, right to self-determination, privacy and confidentiality of research subjects*" (276). College of Medicine Research and Ethics Committee of University of Malawi reviewed and approved study I protocol and the iLiNS-DOSE study protocol, including the activity sub-study and interviews to the parents on 12th of October 2010. The Regional Ethics Committee of Pirkanmaa Hospital District, Finland reviewed and approved study I protocol on 17th of August 2010 and the iLiNS-DOSE trial protocol with activity amendment on 4th of January 2011. The iLiNS-DOSE trial is registered at National Institutes of Health (USA) clinical trial registry with number NCT00945698.

The guardians of the participating children in studies I and II, and the interviewees in study III gave informed consent before enrolling them to the studies. The consents were signed or thumb printed before the enrolment to studies I and II, and in addition a verbal consent was obtained for the activity sub-study in study II. In study III, the consents were voice recorded. For the illiterate guardians in study II, an impartial member of the community witnessed the consent. We kept all the identifiable data, such as video and voice recordings, in files that were encrypted and protected with a password. All the other data were also saved in a password-protected file either within the study office or on the author's computer.

5 Summary of the results

5.1 Background characteristics of participants

In study I, all the participants completed the study (Figure 6) whereas in the study II, 30% of the original 1932 participants dropped out or died during the 12 month intervention period or refused from this activity sub-study (Figure 7). Some of the data were unusable due to accelerometer-related problems (malfunction, data lost during the initialization or devices lost), insufficient amount of wear-time, clock synchronization problems or inability to confirm which participant wore the device (twins in study I). Consequently, 52 participants in study I provided data for the wear-time analysis, 40 for the validation and cut point analysis and 30 for the cross-validation analysis (Figure 6). In study II, 1053 participants had enough data to be analysed for physical activity (Figure 7).

The 56 children in study I were 16.0 to 18.5 months old (mean 17.1) whereas the 1053 children in the study II were 16.8 to 19.5 months old (mean 18.0) (Table 13). The anthropometric characteristics of children in studies I and II were fairly similar and prevalence of stunting and wasting were approximately the same as in the Mangochi area overall.

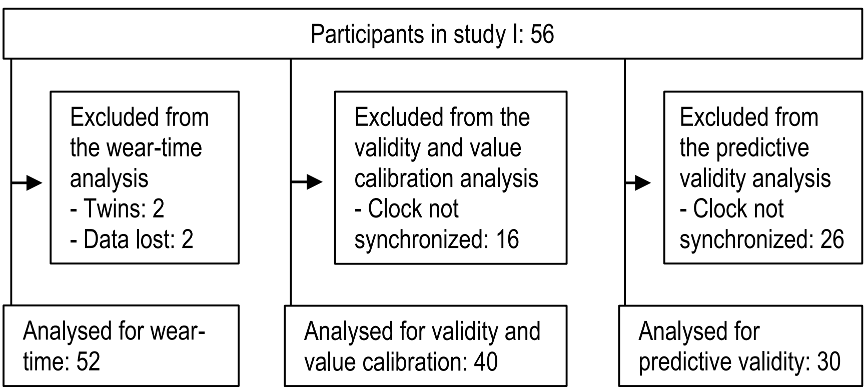
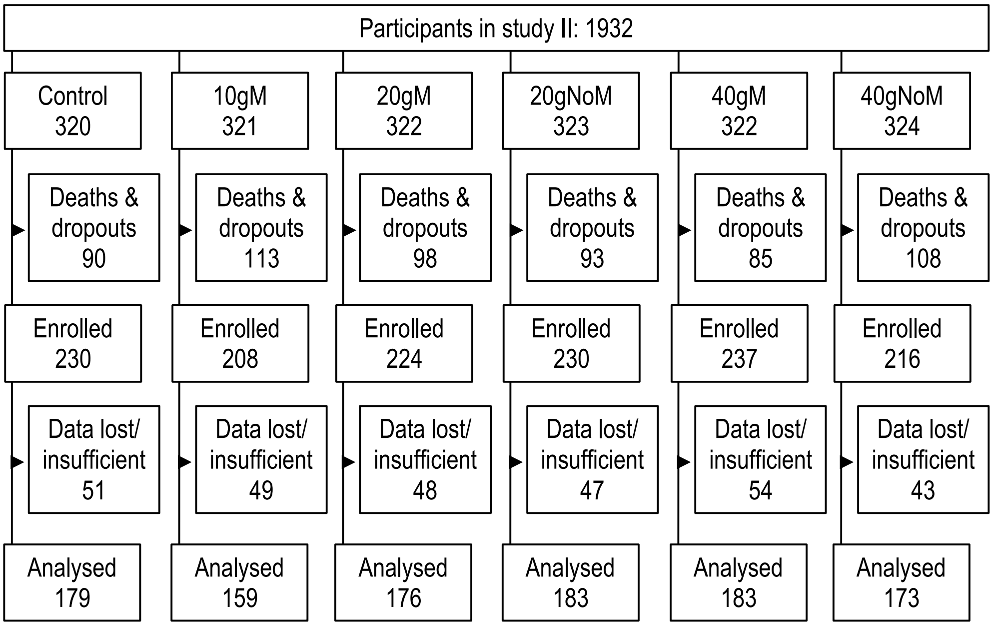


Figure 6. Participant flow in study I



10gM, 10 g milk-containing LNS; 20gM, 20 g milk-containing LNS; 20gNoM, 20 g non-milk-containing LNS; 20gM, 40 g milk-containing LNS; 40gNoM, 40 g non-milk-containing LNS

Figure 7. Participant flow in study II

In study II, the background characteristics of the participants were well balanced between the intervention groups. Those who were analysed had slightly older and less educated mothers and they were more likely to been born in October-December than those who were not enrolled to the activity sub-study or who were enrolled but did not have enough accelerometer data. There were, however, no marked differences in sex, LAZ at enrolment, WLZ at enrolment or HFIAS between the analysed and non-analysed.

For study III, we interviewed 17 parents and two key informants. Six parents attended the focus group discussion. One interviewee was not a parent and the data were not included in the analysis, thus the total number of included parents was 22. Mean age of all the parents was 29 and six of the participants were fathers. Only two of the participants were illiterate. The mean number of children of the responding parents was 2.3 and the mean age of the youngest child was 3.5 years. The interviews lasted from 12 to 39 minutes, mean duration being 23 minutes. The focus group discussion lasted for 35 minutes and the key informant interviews 30 and 40 minutes

Table 13. Background characteristics of participants in studies I and II at the time of accelerometer measurement

	Study I	Study II	
		Enrolled, analysed	Enrolled, not analysed
N	56	1053	292
Mean age, months (SD)	17.1 (0.7)	18.0 (0.4)	N/A
Male, n (%)	24 (43%)	528 (50%)	153 (52%)
Mean length, cm (SD)	75.9 (2.7)	76.2 (3.0)	76.7 (3.1)
Stunted, length-for-age z-scores < -2 SD, n (%)	19 (34%)	449 (44%)	124 (43%)
Wasted weight-for-length z-scores < -2 SD, n (%)	1 (2%)	58 (6%)	17 (6%)
Walk unsupported, n (%)	52 (93%)	959 (95%)	251 (94%)

5.2 Feasibility of using the accelerometer

In study I, 52 participants in the wear-time analysis contributed to 260 days and in study II, 1339 participants to 8696 days of data, after excluding the last and the first day of measurement but including those who did not have enough wear-time or who came to the measurement >30 days after the planned date in study II (Table 14). The children in study I wore the device for somewhat longer periods than children in study II. According to the accelerometer recordings, the median wear-time in study I was 797 minutes (IQR 699 to 849) and in study II 675 minutes (IQR 393 to 784) per day.

Table 14. Accelerometer wear-time in studies I and II

	Study I	Study II
Number of participants (number of days)	52 (260)	1339 (8696)
Median wear-time, min (IQR)	797 (699 to 849)	675 (393 to 784)
% of participants with ≥4 days of 6 hours of data (95% CI)	96% (87% to 100%)	82% (80% to 84%)
% of participants with ≥4 days of 10 hours of data (95% CI)	79% (65% to 89%)	60% (58% to 63%)

Research assistants carried out 258 daily home visits in study I to check how children were wearing the device (Table 15). In study II, these checks were done 1543 times. These included 1381 participants who were checked at the end of the measurement and 148 participants who were visited at home once, twice or three times. In both studies, children wore the device correctly for the majority of the checked times (97% of cases in study I and 90% in study II). Of the incorrectly worn times in study II, almost half were cases when children wore the device on their left hip instead of the right hip. In about third of the cases when the research assistants stated that the child was not wearing the device correctly, they did not specify the explanation how.

The majority of the parents perceived one-week accelerometer measurement non-problematic. At the end of study I, 37 (70%) of the guardians stated that the measurement went "well" and 16 (30%) that it went "mostly well" with no one choosing "it had problems" or "it was very problematic". In study II, the corresponding figures were 1029 (96%) for "well", 37 (3%) for "mostly well", 6 (0.4%) for "it had problems" and 9 (0.7%) for "very problematic", with 2 missing answers. Those who mentioned having problems in the measurement explained that their children were crying when wearing the device or otherwise refused to wear it.

Table 15. Accelerometer device wearing when the data collectors visited the participants

	Study I	Study II
Total number of times the position was checked	258[1]	1543[2]
Times when wearing the device correctly, n (%)	251 (97%)	1384 (90%)
Times when not wearing the device at all, n (%)	4 (2%)	23 (1%)
Times when wearing the device incorrectly, n (%)	3 (1%)	146 (9%)
Explanations: - Not tight	2 (1%)	11 (1%)
- On wrong place		
- Left hip	0 (0%)	60 (4%)
- Back/front	1 (0.4%)	14 (1%)
- Not known	0 (0%)	51 (3%)

[1] Checked at daily home visits, [2] Checked at returning the device and at some home visits

5.3 Value calibration and validity of the accelerometer measurement

Based on the CPAF coding of the video recordings, there was a trend for higher accelerometer counts during epochs of more intense observed physical activity (Table 16). As presented in Table 16, the differences between two consecutive activity categories were statistically significant in light vs. moderate activity in all the measured axes and vector magnitude. In sedentary vs. light activity category, the differences were statistically significant for others than the vertical axis counts. In moderate vs. vigorous activity, only the vertical and the antero-posterior axes showed statistically significant differences.

The ROC curve analysis indicated excellent classification accuracy when comparing sedentary-to-light activity to MVPA. The ROC-AUC was 0.98 (95% CI 0.97 to 0.99) for vector magnitude and 0.95 (95% CI 0.93 to 0.96) for the vertical axis (Table 17). The classification accuracies for comparing two consecutive activity categories to each other were lower. These ROC-AUC values are presented in Table 17 and the ROC curves in figures 8 and 9. Classification accuracy was good for the accelerometer readings between light and moderate activity, but lower for sedentary versus light activity or moderate versus vigorous activity.

Table 16. Median accelerometer counts with interquartile range (IQR) for different observed activity categories

Observed activity category	Vector magnitude counts, median (IQR)	Vertical axis counts, median (IQR)	Antero-posterior counts, median (IQR)	Medio-lateral counts, median (IQR)
Sedentary (n=879)	6 (0 to 41)	0 (0 to 1)	0 (0 to 15)	0 (0 to 24)
p (sedentary vs. light)	<0.001	0.186	<0.001	<0.001
Light (n=150)	58 (17 to 146)	0 (0 to 25)	40 (9 to 85)	32 (0 to 84)
p (light vs. moderate)	<0.001	<0.001	<0.001	<0.001
Moderate (n=361)	443 (294 to 619)	122 (56 to 271)	216 (148 to 305)	289 (172 to 456)
p (moderate vs. vigorous)	0.074	<0.001	<0.001	0.959
Vigorous (n=23)	574 (424 to 682)	206 (109 to 288)	377 (265 to 462)	292 (251 to 480)

Table 17. Receiver operating characteristic area under curve (ROC-AUC) values with 95% confidence intervals (CI) for two consecutive activity categories

Activity category comparison	ROC-AUC (95% CI), vector magnitude	ROC-AUC (95% CI), vertical axis
Sedentary vs. light	0.73 (0.67 to 0.80)	0.62 (0.56 to 0.67)
Light vs. moderate	0.94 (0.91 to 0.97)	0.90 (0.87 to 0.94)
Moderate vs. vigorous	0.67 (0.56 to 0.78)	0.59 (0.47 to 0.72)

Cut points for accelerometer counts were only created for separating sedentary-to-light activity from MVPA, because this showed the best classification accuracy. The best accuracy, i.e. equal specificity and sensitivity, in categorisation of accelerometer counts as compared to observed activity was obtained with cut points of 208 counts/15 s for vector magnitude and 35 counts/15 s for the vertical axis.

To define sensitivity and specificity of the obtained cut point values, we applied them to the 802 epochs in the cross-validation sample. The vector magnitude cut points provided 94.2% sensitivity, 90.9% specificity, 0.86 positive predictive value and 0.96 negative predictive value for capturing moderate-to-vigorous physical activity. Proportion of agreement with observation was 92.1% (kappa 0.83). Corresponding figures for the vertical axis were: sensitivity 84.1%, specificity 84.6%, positive predictive value 0.77, negative predictive value 0.90, agreement with observation 84.4% and kappa 0.67.

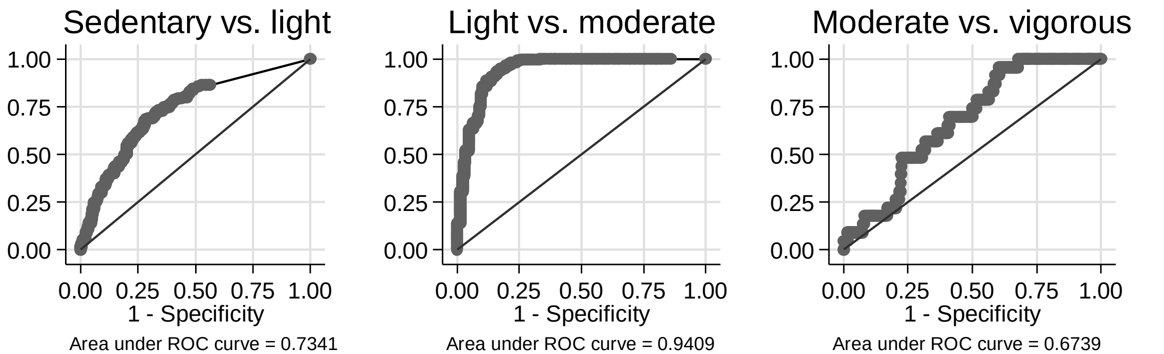


Figure 8. ROC curves for vector magnitude

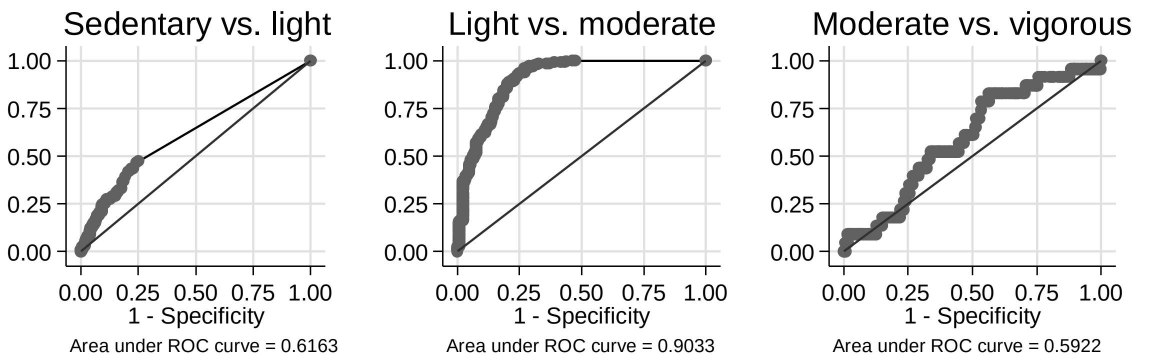
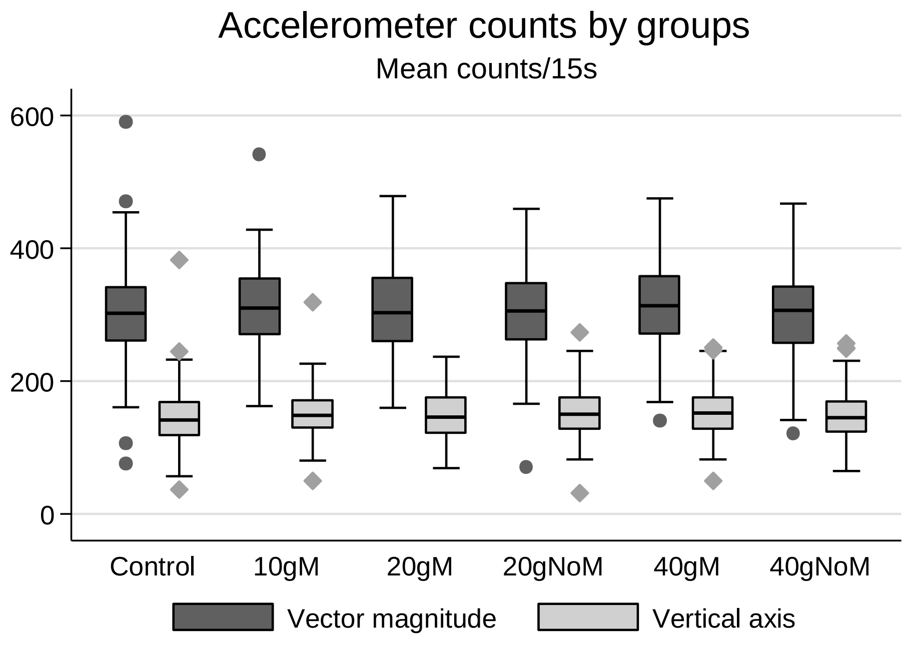


Figure 9. ROC curves for the vertical axis

5.4 Effect of LNS intervention on physical activity

Although children in the control group had slightly lower mean vector magnitude accelerometer counts than children in the five intervention groups, the differences in mean counts were not statistically significant (Figure 10). The mean vertical axis accelerometer counts (Figure 10) and % of time spend in MVPA followed the same pattern, with only statistically significant differences being % time spent in MVPA (vertical axis) among infants in the 20 g non-milk-LNS ($p = 0.046$) and 40 g milk-LNS ($p = 0.032$) groups, as compared to controls (see Table 2 in article II). Results remained essentially similar when activity was adjusted for the participants' LAZ and WLZ at six months, sex, season of birth, maternal education, maternal age, and HFIAS.



10gM, 10 g milk-containing LNS; 20gM, 20 g milk-containing LNS; 20gNoM, 20 g non-milk-containing LNS; 20gM, 40 g milk-containing LNS; 40gNoM, 40 g non-milk-containing LNS

Figure 10. Box-Whisker plots of mean vector magnitude accelerometer counts/15s by LNS groups. Boxes indicate the upper and lower quartiles of activity counts, lines indicate median counts, whiskers span over data points that are within 1.5 IQR of the nearer quartile, outliers are individually marked.

Likelihood ratio test showed an interaction between the intervention and the participants' baseline WLZ. Children who received 20 g milk-LNS, 20 g non-milk-LNS and 40 g milk-LNS and whose WLZ at six months was above the sample median (0.20) had higher mean vector magnitude counts than children in the control group, whereas there were no intergroup differences among participants whose WLZ was below median at enrolment. There were no significant interactions between the intervention and LAZ at 6 months, sex, season of birth, maternal age, maternal education or HFIAS on physical activity.

5.5 Parental perspectives on development and physical activity

The parents and the key informants saw physical activity as a positive attribute of a child, although some of the parents suggested that children who were too active could be seen as uncontrollable or abnormal. Being active was viewed as a sign of being healthy, normal and growing well.

> Sometimes [it] can be good or bad. But mainly it's good. Yes, because if the child is not active, that means he is not growing well. We can think that the child is having a problem. And when the child is active, we understand that the brain is working. (IDI, Mother, 23, English)

Parents perceived activity as both mental and physical quality of a child. Thus being active was well in line with the goals that the parents had for their children: being independent in taking care of basic needs, learning household chores, gaining education and having proper behaviour. Girls were, however, generally expected to be less active than boys although the interviewed parents expressed happiness in their own girls being active.

According to the parents, active children were learning skills early, able to quickly do what the parents asked them to do, playing with other children and healthy as well as had a strong-looking, energetic body. A physically active child was also described in very similar terms as an intelligent child. In addition, parents perceived a physically active child also as one who moves around much. We grouped the factors into four main categories of signs of physical activity: skills acquisition, social competence, health and movement.

> A physically active child is also clever because she knows whatever you are teaching him/her. When you tell her to take something else today and to put

it somewhere else the following day she will do the same and put it on the same place. (IDI, Mother, 23, Chi-Chewa)

A physically active child makes himself busy, she/he has lots of things to do: She/he touches this and stops, she/he does this and stops. She/he has lots to do [participant laughs]. (IDI, Father, 31years, Chi-Chewa)

If children were not active, parents would fear that the children might have problems in their development or that they were sick. Parents described inactive children as ones would just sit still or stay in one place for long periods of time, would not go and play with their friends, were too shy or were fearful in a new environment. Some of the parents also mentioned that inactive children do not do what parents ask them to do and they would look stupid in a group of children because they are beaten by other children.

An inactive child is quiet, she/he doesn't listen, she/he is like a child who doesn't listen. She/he does parallel things to what you told her to do. (IDI, mother, 28 years, Chi-Chewa)

Maybe when his friends come he just stays quiet where you have left him. It's there, or even the face shows that this child isn't very active. (IDI, mother, 21 years, Chi-Chewa)

When asked about facilitators for physical activity, the parents typically first mentioned availability of food and the child being healthy. Parents were concerned about the children receiving balanced diet with enough food. Parents also mentioned that children should be allowed to play with other children and use equipment such as balls or toys to be active. We grouped the facilitators of physical activity as mentioned by parents under three themes: balanced diet, good health and stimulation.

Being active, I will be repeating: it's because of you parents and necessary food for the child not to get sick. The solution is for you to have food. (IDI, Father, 47 years, Chi-Chewa)

6 Discussion

6.1 Structure of the discussion

The aims of this PhD thesis were 1) to test the feasibility and 2) validity of the ActiGraph method in quantifying toddlers' physical activity, 3) to measure effects of LNS intervention on physical activity and 4) to investigate perceptions of Malawian children's parents on physical activity. To meet these aims, we conducted three studies in semi-rural area of Malawi.

The following sections will discuss the main findings, strengths, weaknesses and limitations of the studies in regards to meeting each of the aims. The discussion is constructed in the context of the previous literature on these topics. At the end, some public health implications based on the results are presented.

6.2 Feasibility of the ActiGraph accelerometer

The results from study I demonstrated good feasibility of the accelerometer method as 79% of the participants wore the device for the required minimum of 10 hours for four days. The corresponding figure in study II, 60%, was somewhat lower. The participants were wearing the device in a correct way in 97% of the cases in study I and 90% of the cases in study II. The guardians considered the accelerometer measurement as non-problematic.

The main strength of the feasibility evaluation was the objective assessment of wear-time. This was combined with the guardians' subjective reports of their experiences with the accelerometer method. As a weakness, a bias for more positive responses is possible if the guardians considered reporting positive experiences more socially acceptable.

As a limitation, parameters used in data reduction for the wear-time analysis should be taken into account when comparing the results to other studies. We excluded strings of 20 consecutive minutes of more of zero counts. Although there are no commonly agreed criteria for excluding data, 20 minutes has been used in earlier studies (9,98). Excluding bouts of 20 minutes of zeroes provided a conservative estimate for wear-time as this excluded more time than longer thresholds of 90 (195) or 180 minutes (182) that have also been suggested for older children and adults. Including only days with minimum of 10 hours of wear-time also gave a conservative estimate compared to shorter requirements for a valid day.

Other studies using accelerometers in toddlers have demonstrated feasibility figures within the same range as this study. Van Cauwenberghe and colleagues in Belgium assessed the feasibility of the ActiGraph accelerometer in toddlers aged 12 to 30 months (99). In that study 64% of the participants met the inclusion criteria of having enough wear-time (99). In a study by Hnatiuk and colleagues, 71% of 19-month-old Australian toddlers had enough wear-time (98). As neither of the studies included remainders for the parents, their methods were more similar to our study II. However, the inclusion criteria for valid days in both of the studies were lower than in our studies which might lead to higher estimation of children with enough valid days. The minimum wear-time in the study of van Cauwenberghe and colleagues was 7.7 hours of data for three days (99) and in the study by Hnatiuk and colleagues study 7.4 hours of data for four days (98).

The lower wear-time in study II as compared to study I suggests that the daily home visits by study staff increased the wear-time of the device. However, the method of daily visits would not be feasible in most large-scale studies. We also asked the participants to wear the device continuously during night and day, a method that has suggested to increase compliance by reducing instances when the device is forgotten to put on (181,277). Other strategies to improve compliance include written and verbal instructions, demonstrations, incentives and attaching the device to a part of the body that is comfortable for the participants (18). Apart from highlighting strategies to increase compliance, the observed non-compliance stresses the importance of determining the minimum time required for reliable measurement of activity in the specific age group. The required wear-time has practical implications for the study costs and compliance of participants (198,201) and thus finding the minimum wear-time for reliable measurement would potentially save costs and reduce participant burden.

The participants wore the device in a correct position in majority of the cases, which indicates that the guardians were adhering to the instructions regarding the wear-location. The most common deviation from the instructions was to wear the accelerometer on left hip. According to a previous study testing a uniaxial model of the ActiGraph, the accelerometer counts from devices worn on left and right hip were not significantly different (187). However, a small number of participants in study II wore the device over the back or umbilicus, which might have led to higher readings than from the hip location (189). Overall, slipping of the device from the intended wear-location has been suggested to reduce precision of activity measurements with uniaxial accelerometers in young children (189). It is possible that the differences are smaller with tri-axial accelerometers, but the data on that are lacking.

Our result that guardians reported very few problems with the method is similar as described by Van Cauwenberghe and colleagues in Belgium, who observed none of the parents in their study reporting that the accelerometer measurement was unpleasant for their child (99). A British study suggested towards the same direction as parents of 2 to 3-year-old children who had not worn accelerometers, foresaw no feasibility issues with the ActiGraph accelerometer (215).

6.3 Value calibration and validity of the ActiGraph accelerometer

In study I, the accelerometer counts increased as the observed activity intensity increased although the difference was statistically significant in both vector magnitude and the vertical axis only between light and moderate activity. MVPA cut points of 208 counts/15 s for vector magnitude and 35 counts/15 s for the vertical axis demonstrated the best categorization accuracy defined as equal specificity and sensitivity.

The strengths of study I in regards to assessing the validity of the ActiGraph method included employing free play sessions, using an appropriate criterion method, including a relatively large sample of children and applying ROC curve analysis. Using a variety of activities from a wide range of activity intensities that represent the typical movement pattern for that population has been recommended for studies validating accelerometers (193,203,204,207) as this increases the external validity of the results. Including a wide range of activities is especially important with young children who accumulate most of their activity in free play (193). Observation as a criterion method is well-suited for calibrating count cut points for different activity intensities in children (203,204,207) because in young children measurement and interpretation of energy expenditure is difficult (204). To increase internal validity, we only included epochs where one intensity of activity was present throughout the 15 second epoch. Sample size of 40 children in the cut point calibration exceeded the suggested minimum sample size of 10 participants per age group (204). ROC curves are one of the methods of choice for calibration studies because they allow examination of trade-offs between sensitivity and specificity for all the possible cut points (204).

The weaknesses of study I in regards to assessing the validity of the accelerometer method are related to the CPAF observation as the criterion method. Although many consider observation to be a criterion measure for assessment of physical activity (38,138,141,207), others claim that it is inherently a subjective method as it requires interpretation of the activity by the observers (95). This was highlighted in the relatively low inter-observer agreement in study I. In addition, the CPAF method has not been validated in the toddler age group but with children aged 8 to 10 years (156) although it has been widely used in studies assessing activity of pre-schoolers (95,152,212). CPAF was originally validated against heart rate measurement (156). As the CPAF method has not been validated against energy expenditure, the activity categories obtained with CPAF method do not necessarily correspond with MET-values for sedentary, light, moderate and vigorous activities. As a limitation, the results of study I might not be generalised in populations where children are larger in size or attend very different activities in their free play.

Accelerometer counts increased when the observed activity level was higher. These results are in line with the study of Van Cauwenberghe and colleagues, who found positive correlation between OSRAC-P observation and uniaxial ActiGraph accelerometer counts in toddlers aged 12 to 30 months (99).

The vertical axis cut point of 35 counts/15 s for MVPA defined in this study is considerably lower than 418 counts/15 s defined by Trost and colleagues among toddlers aged 16 to 35 months in US. The vertical axis and vector magnitude cut points are also considerably lower than 165 counts/5 s defined by Costa and colleagues, although the comparison is difficult due to the different epoch length of 15 seconds in our studies compared with 5 seconds used by Costa and colleagues (208).

Variation in cut points defined by different methods is common. For example, the Trost toddler cut points are close to MVPA cut point of 420 counts/15 s defined by Pate and colleagues among pre-schoolers aged 3 to 5 years (105,211). Another cut point developed for the same age group to catch MVPA by Sirard and colleagues is considerably higher, 615 counts/15 s (106). The Costa vertical axis cut points of 165 counts/5 s (208) are in the magnitude between the Pate and Sirard cut points. Of the pre-schoolers cut points, Van Cauwenberghe and colleagues concluded that the Pate cut points provided the best level of agreement with observed physical activity of toddlers aged 12 to 30 months (99).

There are several possible explanations for the discrepancies between this and other toddler cut points, including the exact criteria used for selecting the cut point from the ROC curve. The high ROC-AUC values of 0.94 for vector magnitude and 0.90 for the vertical axis in our study indicated good classification accuracy between MVPA and lighter activity, but choosing the cut point from the ROC curve is not straightforward. When selecting a cut point, one can emphasise either sensitivity or specificity or both (278). It is difficult to estimate the impact of different ways of selecting the cut point from the ROC curve as many of the studies using the method do not report the exact selection criteria (105,208). In practise, maximising both sensitivity and specificity (106) might mean selecting the cut point where either sum or sum of the squared sensitivity and specificity are maximised (278). It is worth noting that this cut point does not usually correspond to the maximum value of sensitivity or the maximum value of specificity (278). We chose to use the point where sensitivity and specificity were equal, although it was slightly different than the cut point that maximised the sum of sensitivity and specificity. In addition, we offered a table presenting the sensitivity and specificity of different possible cut points as a supplementary table S2 to article II.

Some other possibilities for the discrepancies in cut points between different studies include the observation system that was used for criterion method, activity patterns that the children demonstrated and size of the children. We classified all CPAF category 3 (slow trunk movement) activities into moderate activity, which might have overestimated the amount of moderate activity compared to another commonly used observation method, CARS, which makes a distinction between slow and moderate translocation (158). As the second year of life is the time of dramatic change in motor ability (9,66), it is possible that the movement pattern of the 16 to 18-month-old toddlers in our study were still immature compared to the somewhat older children in the earlier toddler studies (105,208). This could have influenced the different values captured by the accelerometers especially in the high activity intensity. Furthermore, the toddlers in our study were shorter in length and lighter in weight than their counterparts in the high-income countries, which could have further contributed to the differences.

6.4 Effect of LNS on physical activity

In study II, mean accelerometer counts and % of time spend in MVPA at the end of the intervention, at 18 months of age, were not statistically significant in the intervention groups as compared to the control group. The results remained essentially similar after adjusting for several background variables.

The main strengths of study II included the use of randomised controlled trial design and an objective measurement of the activity outcome. We used randomisation to control for confounders and to decrease selection bias. To ensure equal enrolment to study groups across different seasons, we did randomisation in blocks. Background characteristics of participants were well balanced between trial groups suggesting that the randomisation was successful. To decrease observation bias, the study staff assessing outcomes were blinded to the group allocation. Further strength of the study included the enrolment method and the wide inclusion criteria which allowed for minimising selection bias and enrolling a representative sample of children in these areas of Malawi. All age-eligible children were first identified through community surveys and then invited for the study clinics for detailed enrolment evaluation. As a result, the enrolled participants were similar as the children in the area at least in regards to height, weight and socioeconomic background (262).

The weaknesses of study II include relatively high loss to follow-up, no objective information on compliance with the LNS feeding recommendations, not being able to blind the guardians for the intervention allocation of their children and no baseline measurement for physical activity. Those who contributed to enough activity data were 55% of the original iLiNS-DOSE cohort but they were mainly similar to the children in the main intervention trial who were not enrolled to this sub-study or who were enrolled but did not have enough accelerometer data. We collected information on the compliance of feeding the children with LNS by collecting the empty jars every two weeks and interviewing the guardians. Although the guardians reported 92% compliance of the children consuming the LNS, they also reported deviations from the instructions of using the supplement, such as sharing or not mixing LNS with food (279). Loss to follow-up and low compliance can reduce statistical power of the study. However, there were no significant differences in the rate of loss to follow-up or non-compliance between the trial groups which indicate that these did not contribute to systematic error. Although the guardians who are aware of their children's intervention allocation can increase observation bias by reporting e.g. more or less symptoms if their child was in the intervention group, it is unlikely that this would have affected the accelerometer measurements. Furthermore, because of the lack of baseline measurement for physical activity we were not able to assess the change in physical activity level during the intervention or e.g. assess the effect of the intervention in children who were less active at the baseline.

As a limitation, the results of study II cannot be generalised out of the context of children and parents in semi-rural Malawi. Furthermore, there is currently no consensus on methods for accelerometer data collection and data reduction. Therefore, the choices made in study II (right hip placement, 15 s epoch, exclusion of night time and strings of 20 minutes of zero counts, minimum data of 6 hours from 4 days and Pulakka and Trost (105) cut points) have to be taken into account when comparing the results with other studies. Different epoch lengths can result to different amount of time in MVPA. For example, some studies show that longer epochs can underestimate (191) or overestimate (280,281) time in MVPA compared to shorter epochs in pre-schoolers and school-aged children. However, shorter epochs, such as 5 s, seem to catch more vigorous or very vigorous physical activity in children than longer epochs (188,191,280,281), and thus the 15 s epoch we used might have missed some vigorous physical activity.

As this was the first study to assess the effect of LNS supplementation on physical activity, there are no earlier studies to directly compare the results to. Studies using other nutrient interventions have obtained varying results. Positive effect of nutrition intervention to physical activity was found with 4-month supplementation by multiple micronutrients (257), 7-month supplementation by 10 mg zinc sulphate (256) and 6-month supplementation by 10 mg of elemental zinc (255) among nutritionally at-risk children. In addition, 12-month supplementation by micronutrients and condensed or skimmed milk demonstrated no effect on physical activity among children who started the supplementation at 18 months of age, but higher physical activity among anaemic children and children who started the supplement at the age of 12 months (254,258). A study assessing 24-month supplementation of stunted children by milk-based nutrient supplement did not find increase of activity (243). Generally, these earlier studies have used smaller sample sizes and shorter duration of intervention than what was used in study II, as well as relatively short direct observation as the physical activity measurement method.

Possible explanations of the LNS intervention not having effect on physical activity include low compliance of consuming the LNS, supplement replacing breast milk intake and children not having a deficiency in activity to start with. In addition, infections might interact with nutrition in a way that decreases the effects of nutrition intervention.

The reported compliance in the study was relatively high (279) and the dose-to-mother deuterium oxide dilution assessment done at the age of 9 to 10 months indicated no reduction of breast milk intake in the infants receiving the LNS intervention (282). Although the differences in accelerometer methodology prevent direct comparison, there is some indication that the children in study II had approximately similar activity levels as toddlers in high-income countries, despite the prevalence of stunting among children in our study being > 40% at the time of the accelerometer measurement. Van Cauwenberghe and colleagues observed mean vertical axis counts of 126 counts/15 s during weekdays and 115 counts/15 s during weekend days among 12 to 30-month-old Belgian toddlers (99). Wijtzes and colleagues reported mean vertical axis counts of 577.2 counts per minute during weekdays and 610.5 counts/60 s during weekend days among 25-month-old Dutch toddlers (104). These translate to 144 counts/15 s for weekdays and 153 counts/15 s during weekend days. We excluded strings of 20 minutes or more consecutive zeroes, which might lead to including more sedentary time than with the 10 minutes exclusion criteria used in both the Dutch and the Belgian study, but the obtained 145 to 153 vertical axis counts/15 s across the intervention groups still appear to be about as high or higher than in the two other studies.

Recurring infections have the potential to reduce the effects of nutrient intervention (225). Infections impair the absorption of nutrients, decrease appetite, and increase nutrient losses (283). To support catch-up growth, the energy requirements of children increase above the normal levels after infections (283). Therefore, it is possible that nutrition interventions are not sufficient alone but interventions that aim to improve children's well-being need to target other risk factors, such as infections (225,229,284).

6.5 Malawian parents' perceptions of physical activity

Study III was carried to widen the perspective of this thesis by including a qualitative inquiry of parents' perspectives to physical activity, as parents have a key role in influence young children's physical activity. The interviewed parents considered learning skills early, being socially skillful, staying healthy and moving around much as signs for children being active. They listed e.g. fetching things, doing what is asked, performing well at school, playing with other children, running and jumping as activities that an active child would do. The parents viewed balanced diet, being healthy and getting stimulation from other people and play equipment as facilitators for activity.

The strengths of study III included varied background of the interviewees, use of local language in part of the data collection, voice recording and using triangulation and peer debriefing to increase credibility of the results. Although the enrolment was done with convenience sampling, the interviewed parents presented a variety of backgrounds in regards to gender, number and age of children, educational background, literacy and occupation. Voice recording increased verbal accuracy of the data and allowed data to be transcribed verbatim (285,286). The data sources were triangulated by interviewing both parents and key informants who had an extensive experience of working as a nurse in the study area. We also used peer debriefing, i.e. discussing the results with colleagues (286), both to evaluate the author's own role in the analysis and to find out whether researchers who have deep insight into the culture of the research area agree with the findings (274).

A weakness of study III was that the participants were slightly biased towards more educated parents. Two of them were also participants in the ongoing nutrient supplementation study (iLiNS-DOSE), which could have biased their perceptions of nutrition but was unlikely to affect their views on physical activity because the activity measurements were conducted after the interviews of study III.

The parents' description of physical activity was very different from the scientific definition where physical activity is considered as any movement of skeletal muscles that increases energy expenditure (30,31). The parents viewed physical activity more comprehensively than only bodily movement and described it in the context of everyday living. This was also different than what was found in previous studies in Australia and New Zealand, where parents of young children described physical activity as bodily movement (127) or exercise (128), but did not mention cognitive or social skills.

Similarly to previous studies, the parents described their children currently as being active. They also described the activity differences between girls and boys in a very similar manner as Australian pre-school children's parents in the study of Hinkley and colleagues: boys were generally expected to be more active than girls, but there were differences between individuals (135).

The types of activities that the Malawian parents described as physical activity have both similarities and differences with the views of parents from high-income countries presented in previous studies. Running, jumping and climbing trees are examples of activities mentioned both by the Malawian parents and parents from high-income countries (127,130,131). In addition, the Malawian parents mentioned types of activities that were not described in the studies from high-income countries such as fetching things, performing well at school and having good behaviour. On the other hand, parents from high-income countries brought up organized activities or activities that need special equipment, for example rollerblading, jumping on a trampoline or running on a treadmill as part of the definition of physical activity (127,130). These were not mentioned by the Malawian parents.

Issues related to stimulation, such as companionship with children and adults and having access to play equipment, have been reported as facilitators for children's activity according to parents in Europe, North America and Australia, but the emphasis for enough food was not described in these studies (127,130-136). However, the studies describing parents' views on child development suggest that parents who are from low-income settings place importance on fulfilling basic needs (287,288).

Generally speaking, parents want their children to acquire skills that enable them to function adaptively in the local communities (289). In this study, the goals that parents had for their children encompassed practical skills, good behaviour and formal education. Emphasis of good behaviour and practical skills as an important child rearing goals is consistent with previous research in Malawian (290,291) and other sub-Saharan African settings (287,292). The finding that parents placed high value to schooling in the future of the children is also in line with other studies from low-income settings, for example Egypt (293), South Africa (294) and Kenya (295). The parents expressed coexistence of both collective goals (the children should have good behaviour, respect others and be able to support parents) and individualistic goals (the children can make their own decisions regarding their future). This coexistence has been described in many forms and contexts earlier (289,296).

6.6 Public health implications and future research directions

Based on the literature review and the studies included in this thesis, the accelerometer is feasible to be used by toddlers aged 1.5 to 3 years and the method is well accepted by their parents. The wear-time of the device might be increased with remainder visits.

The ActiGraph GT3X accelerometer is a valid method for assessing physical activity of toddlers aged 16 to 18 months and it can be used in future studies where objective measurement of physical activity is preferred. Because of substantial variation between established accelerometer count cut points for this age group, further studies are needed establish ideal cut points for different physical activity intensities.

In this study, 12-month intervention with different doses of LNS did not impact physical activity of young children in an area with high prevalence of chronic undernutrition. Interventions that aim to improve children's well-being may need to target other risk factors than nutrition alone. The activity level of toddlers in our study was relatively similar to that of toddlers in high-income countries. There is a growing concern that this level of activity is not enough to support future health and good development. As the current recommendations are mainly based on data from questionnaires, further studies are warranted to provide activity recommendations for toddlers based on objectively measured physical activity.

The Malawian parents in our study described physical activity very differently from the scientific definition but viewed it as a positive attribute of the children. As parental attitudes have impact on children's physical activity, the positive attitudes towards activity are beneficial in public health's perspective. The parents' broad view to physical activity is markedly different from accelerometer-measured physical activity, which only measures movement of the body and cannot describe the context where that movement happens. To convey messages in public health programs, professionals should be aware of the possible differences of lay definition of physical activity and be explicit about their message of physical activity. Lay perceptions of physical activity should also be taken into account also when planning physical activity questionnaires so the questions and examples used are relevant in the cultural context.

7 Conclusions

The main findings of this thesis can be summarised as follows:

1. Feasibility of the ActiGraph accelerometer: ActiGraph accelerometer provides a feasible way to study physical activity of toddlers. The toddlers are able to wear the device for a sufficient time for reliable measurement. The parents were mostly satisfied with using the device on their toddler and reported only few problems.

2. Validity of ActiGraph accelerometer: The ActiGraph accelerometer is a valid method for quantifying physical activity of toddlers. The highest classification accuracy was observed between light and moderate physical activity. ActiGraph accelerometer count cut points of 208 counts/15 s for vector magnitude and 35 counts/15 s for the vertical axis have excellent sensitivity and specificity for differentiating between MVPA and lighter physical activity.

3. Effect of lipid-based nutrient supplement (LNS) on physical activity: The results do not support the hypothesis that 12-month provision of small-quantity LNS increases physical activity of Malawian toddlers.

4. Perceptions of Malawian parents on physical activity: Malawian parents consider physical activity as both mental and physical feature of young children and describe active children as ones who acquire practical and cognitive skills early, are socially competent, healthy and move around much. According to them, being physically active is mainly a positive characteristic of a child and well in line with the goals that they have for their children. As facilitators for physical activity the parents place emphasis on balanced diet and good health but they also consider having other people and equipment to stimulate children to be active as facilitators of activity.

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10 Original publications

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REGULAR ARTICLE

Feasibility and validity of the ActiGraph GT3X accelerometer in measuring physical activity of Malawian toddlers

A Pulakka (anna.pulakka@uta.fi)[1], YB Cheung[2,3], U Ashorn[1], V Penpraze[4], K Maleta[5], JC Phuka[5], P Ashorn[1,6]

1.Department of International Health, University of Tampere School of Medicine, Tampere, Finland
2.Centre for Quantitative Medicine, Duke-National University of Singapore Graduate Medical School, Singapore, Singapore
3.Department of Biostatistics, Singapore Clinical Research Institute, Singapore, Singapore
4.School of Life Sciences, University of Glasgow, Glasgow, UK
5.Department of Community Health, University of Malawi College of Medicine, Blantyre, Malawi
6.Department of Pediatrics, Tampere University Hospital, Tampere, Finland

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Correspondence
A Pulakka, Department of International Health, University of Tampere School of Medicine, Tampere 33014, Finland.
Tel: +358 44 5749920 |
Fax: +358 3 35516164 |
Email: anna.pulakka@uta.fi

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ABSTRACT

Aim: To test the feasibility and validity of the ActiGraph GT3X accelerometer in measuring physical activity of rural Malawian toddlers.

Methods: Fifty-six children aged 16.0–18.5 months wore the accelerometer on their right hip for 7 days. We analysed days with a minimum of 600 min of wear time, excluding night time and periods when the unit registered zero for 20 consecutive minutes. The first and last days were excluded as they were incomplete. Accelerometer counts were compared with coded free play video recordings to define median accelerometer counts for sedentary, light, moderate and vigorous activity. Count cut points were defined for moderate to vigorous physical activity, with predictive validity assessed using a second set of video recordings.

Results: Median wear time was 797 min/day, with 79% of participants completing at least four eligible days. Accelerometer counts were significantly higher for observed moderate to vigorous physical activity, than lighter activity, with cut points of 208 counts/15 sec for vector magnitude and 35 counts/15 sec for vertical axis, showing sensitivity of 94.2% and 84.1% and specificity of 90.9% and 84.6%, respectively.

Conclusion: The accelerometer proved a feasible and valid method of assessing physical activity among Malawian toddlers.

INTRODUCTION

On a global level, the well-being of infants and young children is typically expressed through variables that indicate mortality or growth (1,2). Additional outcomes that are particularly used to assess nutritional interventions in low-income settings include laboratory analyses of micronutrient status, morbidity and development (3). While these sets of outcomes undoubtedly have their benefits, each of them also has deficiencies, such as lack of sensitivity (mortality indicators), specificity (growth), external validity (many development assessment methods) or ease of assessment (morbidity, micronutrient status). As a result, there is a need to develop new indicators that could be used in trials or in interventions that address the well-being of infants and young children.

One potential indicator for the overall well-being of children, and a possible determinant of both their cognitive and motor development, is their physical activity (4–6). Measuring physical activity has recently become much easier with the use of accelerometers, small devices that can record body movements over extended periods of time and in nonclinical environments, such as at home (7,8). Accelerometers have increasingly been used to provide objective

Abbreviations
CI, 95% Confidence interval; CPAF, Children's Physical Activity Form; MET, Metabolic equivalents; MVPA, Moderate to vigorous physical activity; ROC-AUC, Receiver operating characteristic area under curve; ROC, Receiver operating characteristic; SD, Standard deviation.

Key notes

- Accelerometers are widely used to measure physical activity among adults and older children in high-income settings, and their use is expanding to younger populations.
- The ActiGraph GT3X accelerometer proved a valid and feasible method for measuring activity among toddlers in a sub-Saharan African setting.
- This study suggests cut points for moderate to vigorous physical activity of 208 counts/15 sec for vector magnitude and 35 counts/15 sec for vertical axis for toddlers.

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measurements of physical activity, especially among adults and older children in industrialised countries, because they are easy to use, provide a numerical read-out and are relatively inexpensive (7,9). However, there have been concerns about compliance when using accelerometers with toddlers (8,9), and so far only one study has addressed this issue (10). In addition, there have been no reports on the validity of the accelerometer method in sub-Saharan Africa or other low-income settings.

The aim of this study was to assess the feasibility and validity of using an accelerometer to quantify physical activity among toddlers aged between 16 and 18 months in rural Malawi. A group of 56 toddlers were recruited to test the wear time of a specific accelerometer model, the ActiGraph GT3X, and to gauge their guardians' opinions on the method. We compared the accelerometer counts with video recordings of the children's activity and determined cut points for moderate to vigorous physical activity (MVPA). Finally, we tested the specificity and sensitivity of the method by applying the defined cut points to a second set of observations from the same study participants.

METHODS

Participants

In this cross-sectional study, 56 participants (32 girls and 24 boys) were recruited from Lungwena, a rural area in Malawi. A sample size of at least 50 participants was chosen to provide precision of at least ±15% for estimating the prevalence of wearing the device for a minimum of 4 days. Children were eligible to participate if they were 16–18 months old and resided in the study area. Children with chronic illnesses and those who were wasted (weight-for-height z-score < -2SD) were excluded. The College of Medicine Research and Ethics Committee of the University of Malawi reviewed and approved the study protocol in advance. Guardians of all the participants gave informed consent before enrolment, and this was documented by either a signature or a thumbprint.

Protocol

A research coordinator asked the village headmen to identify children of a suitable age and invite them to attend the study clinic to have their eligibility assessed. At the clinic, trained research assistants measured the children's weight to the nearest 0.01 kg using an electronic scale (OBH Nordica 6201; OBH Nordica, Stockholm, Sweden) and their height to the nearest 0.1 cm using a length board (Kiddimetre; Raven Equipment Ltd, Essex, UK). The children's date of birth was obtained from their health passports.

Research assistants fitted children eligible to take part in the study with an ActiGraph GT3X accelerometer (Pensacola, FL, USA), using an elastic band to secure it to their right hip. The ActiGraph GT3X is a small tri-axial accelerometer weighing 27 g and measuring 3.8 cm × 3.7 cm × 1.8 cm. It records accelerations ranging from 0.05 to 2 g at a rate of 30 Hz in three different axes: vertical, antero-posterior and medio-lateral (11). Vector magnitude is a variable that combines information from these three axes and is calculated by taking the square root of the sum of the squared activity counts of each axis. An epoch length of 15 sec was set prior to the measurements, according to the recommendations of accelerometer measurements for young children (8,9,12). Research assistants told the guardians to ensure that the children wore the accelerometer throughout the day and night without any breaks, unless they showed signs of discomfort. However, they were told to remove it when the child had a bath.

During the 7-day measurement period, a research assistant visited the participants once a day to check that they were wearing the device snugly on the right hip. At the end of the measurement period, the research assistants completed a local-language questionnaire with the guardians, asking them for their comments on the measurement process and the child's response to it. The responses were classified into four categories as follows: 'went well', 'went mostly well', 'had quite a lot of problems' and 'was very problematic'. No details of sleep, nap or bath times were collected.

Research assistants recorded the participants wearing the accelerometer during two free outdoor play sessions at their homes using a digital video camera (Canon FS-306; Canon Inc, Tokyo, Japan). The sessions were a minimum of 3 days apart and lasted for at least 60 min. A researcher (AP) synchronised the video camera clock with the computer that was used for initialising the accelerometers and checked the synchronisation several times a week. The researcher also analysed the last 30 min of each video recording using the Children's Physical Activity Form (CPAF) (13).

The CPAF method uses four levels to categorise physical activity intensity: (i) stationary, no movement; (ii) stationary, limb movement; (iii) slow trunk movement and (iv) rapid trunk movement (13). The method was modified to fit the 15-sec epoch length. The amount of time analysed for each participant ranged from 30 min to 38 min (121–151 observation epochs). CPAF category (i) is considered sedentary, category (ii) light, category (iii) moderate and category (iv) vigorous activity. These categories do not, however, refer to the commonly used physical activity categorisations according to metabolic equivalents (METs). Only 'clean' epochs – where one class of activity intensity was observed for the entire duration of the epoch – were included into the analysis. To assess interobserver validity of the method, a second independent observer (VP) rated 19.5% of the recordings. Interobserver agreement for clean epochs was 60%, kappa 0.35. Intraobserver agreement for the first observer (932 epochs, with 10% double-coded) was 83%, kappa 0.61. For the second observer (1719 epochs with 100% double-coded), it was 92%, kappa 0.88.

Data reduction and analysis

Data were analysed with Stata/IC software, version 11.2 (StataCorp, College Station, TX, USA). Strings of zeros for 20 consecutive minutes or more were not included in the wear time analysis. Night-time was estimated using the activity pattern recorded by the children's accelerometers, and the period from 8 p.m. to 5 a.m. was excluded from the analysis as a result. In addition, the first and the last days of measurement were also excluded, as they were incomplete days. This resulted in a maximum wear time for each participant of 900 min (15 h) per day for 5 days. An eligible day for statistical analyses was defined as minimum of 600 min (10 h) of wear time. The proportion of participants who were compliant with using the device – defined as a minimum of four eligible days – was calculated with a 95% confidence interval (CI), based on binomial distribution. We found no recommendations for the minimum amount of data needed for reliable measurement for this age group. However, 600 min for 4 days had been suggested as a suitable measurement for older children (12,14,15), and we decided to use the same parameters in the current study.

The first video-recorded observation session was used to validate the ActiGraph method against direct observation and to establish accelerometer count cut points to differentiate MVPA from lighter activity. The analyses were carried out separately for the vector magnitude and vertical axis. Vertical axis was chosen to allow comparisons with the older, one-axial, model of the ActiGraph device. Data from the analysis of the video recordings were only included when the child was visible for the whole duration of the epoch, the child was not being lifted or carried by another person, and the clocks were well synchronised between the video camera and the ActiGraph device.

The working hypothesis that our research would show a direct and positive association between the ActiGraph counts and the observed activity category was tested with quantile regression. Two consecutive categories were compared with each other, taking into account the cluster effect of multiple epochs for each participant. The level of statistical significance was set at 0.05.

Classification accuracy of the accelerometer counts was assessed by receiver operating characteristic (ROC) curve analysis, which graphically displays the trade-off between sensitivity and specificity for each possible cut point value (16). ROC curves with area under curve (ROC-AUC) were independently determined for light versus sedentary, moderate versus light and vigorous versus moderate activity. The 95% confidence intervals for ROC-AUCs were obtained by bootstrapping, taking the cluster effect of multiple epochs per participant into account. For cut point analysis of MVPA, a ROC curve separating MVPA from light to sedentary activity was determined. The cut points showing equal levels of sensitivity and specificity were chosen. These cut points were then applied to the cross-validation sample of the second video recordings to determine sensitivity and specificity.

RESULTS

Of the 68 children who were assessed for the study between October and December 2010, 56 were eligible and enrolled. Of these, 52 provided data for the wear time analysis, 40 for the validation and cut point analysis and 30 for the cross-validation analysis. Figure 1 presents details of the participants and summarises the accelerometer data for the various types of analyses. Table 1 summarises the background characteristics of the participants included in the three types of analyses: wear time, validation and cut points and cross-validation.

According to the activity recorded by the accelerometer, the median wear time was 797 min per day (interquartile range 699–849; range 1–900). The majority of the participants (n = 41, 79%, CI 65–89%) had four or five eligible days with at least 10 h of data. Five participants had three eligible days, one had two eligible days, four had one eligible day and one participant had no eligible days. When the research assistants checked the children at home, 97% (CI 95–99%) were wearing the device correctly. All of the guardians (n = 53) said that overall the measurement went 'well' or 'mostly well'. One mother said that she changed her child's daily routines because of the measurement, and one said that her child reacted slightly to the device by crying on the first few days.

Figure 2 presents the distribution of accelerometer counts by observed activity intensity class. The analysis consisted of 747 sedentary, 144 light, 351 moderate and 23 vigorous epochs. As shown, there was a trend for higher accelerometer counts during epochs of more intense observed physical activity, with median vector magnitude counts of 6 for sedentary, 58 for light, 443 for moderate and 574 for vigorous activity. Corresponding median counts in the vertical axis were 0, 0, 122 and 206 for the same activity classes, respectively. Only light versus moderate activity showed statistically significantly ($p < 0.001$) different counts in both vector magnitude and the vertical axis. Analyses using accelerometer counts from the antero-posterior and medio-lateral axes gave essentially similar

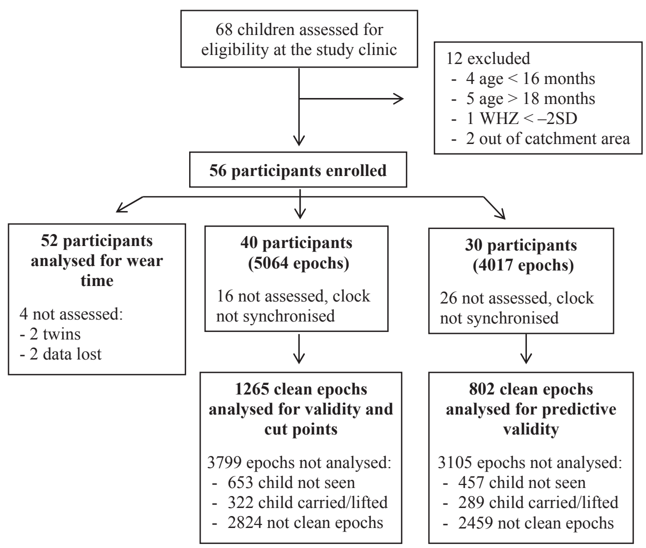

Figure 1 Inclusion of participants and epochs of different analyses.

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Table 1 Background characteristics of participants

	Total sample (n = 56)	Wear time (n = 52)	Validation and cut point (n = 40)	Cross-validation (n = 30)
Age (months), median (range)	17.0 (16.0–18.5)	17.0 (16.0–18.5)	16.9 (16.0–18.3)	17.0 (16.0–18.3)
Male, n (%)	24 (43)	23 (44)	16 (40)	12 (40)
Length (cm), mean (SD)	75.9 (2.7)	75.9 (2.7)	75.6 (2.9)	75.3 (2.1)
Length-for-age *z*-scores (LAZ), mean (SD)	−1.64 (0.97)	−1.62 (0.95)	−1.68 (1.03)	−1.80 (0.79)
Weight-for-height z-scores (WHZ), mean (SD)	−0.11 (1.08)*	−0.08 (1.10)†	−0.30 (0.94)	−0.17 (0.96)
BMI, mean (SD)	16.4 (1.6)*	16.4 (1.7)†	16.1 (1.4)	16.3 (1.4)
BMI *z*-score, mean (SD)	0.21 (1.1)*	0.23 (1.1)†	0.02 (1.0)	0.19 (0.9)
Walk unsupported, n (%)	52 (93)	48 (92)	36 (90)	26 (87)

*n = 55.
†n = 51.

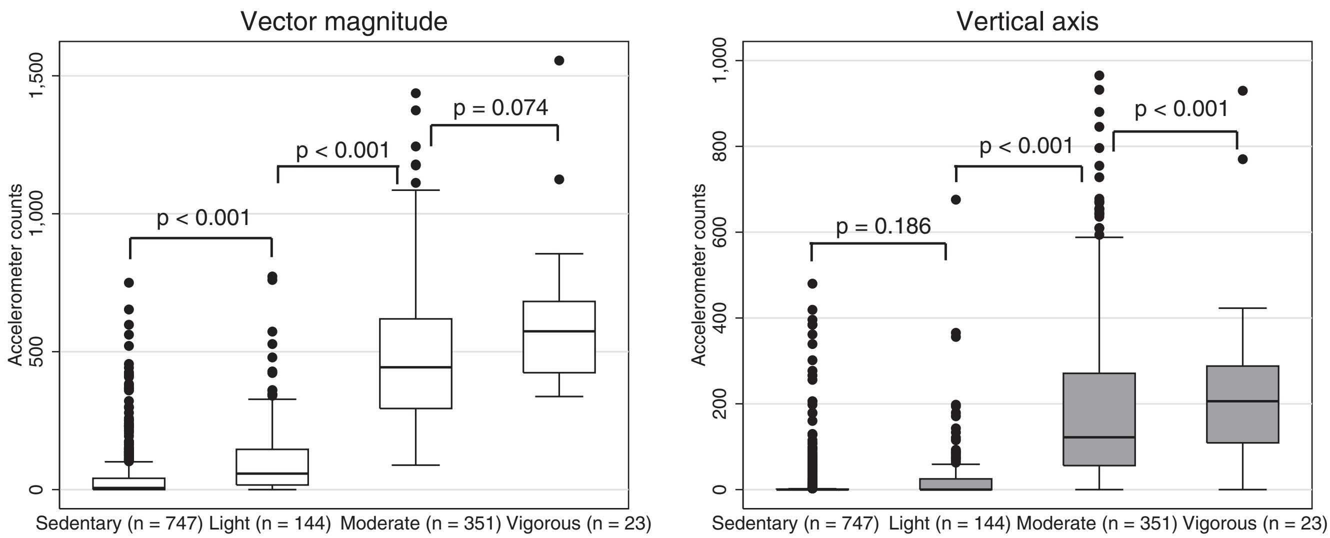

Figure 2 Accelerometer counts for different observed activity categories (number of epochs), vector magnitude and vertical axis.

results to those shown above (Table S1). Further characterisation of some epochs, when the participant was categorised as being sedentary or engaged in light activity but the accelerometer yielded high counts, indicated that these epochs were often associated with brief trunk movements that were probably ignored by the observers.

A ROC curve analysis indicated good classification accuracy for the accelerometer between light and moderate activity, with an ROC-AUC of 0.94 (CI 0.91–0.97) for vector magnitude and of 0.90 (CI 0.87–0.94) for the vertical axis (Fig. S1). The ROC curve analysis also showed excellent classification power between sedentary to light and moderate to vigorous activity, with an ROC-AUC of 0.98 (CI 0.97–0.99) for vector magnitude and of 0.95 (CI 0.93–0.96) for the vertical axis (Fig. 3). Classification accuracy was not as good for sedentary versus light activity, with an ROC-AUC of 0.73 (CI 0.67–0.80) for vector magnitude and of 0.62 (CI 0.56–0.67) for the vertical axis. When it came to moderate versus vigorous activity, the ROC-AUC was 0.67 (CI 0.56–0.78) for vector magnitude and 0.59 (CI 0.47–0.72) for the vertical axis (Fig. S1).

Because of the results on classification accuracy, cut points were only created for separating sedentary to light from moderate to vigorous activity, as shown in Figure 3. Compared with the observation method, the best categorisation accuracy (equal specificity and sensitivity) was observed with cut points of 208 counts/15 sec for vector magnitude and 35 counts/15 sec for the vertical axis. A sample of alternative cut points and their corresponding sensitivity and specificity is presented in Table S2a,b.

Finally, these obtained values were applied to the 802 epochs in the cross-validation sample to define sensitivity and specificity of the aforementioned cut points against observed activity. Table 2 shows a cross-tabulation between the activity categories derived from the ActiGraph and from observations. Based on the chosen cut points, the sensitivity and specificity were 94.2% and 90.9% for vector magnitude and 84.1% and 84.6% for the vertical axis. The corresponding proportion of agreement with observation was 92% (kappa 0.83) for vector magnitude and 84% (kappa 0.67) for the vertical axis.

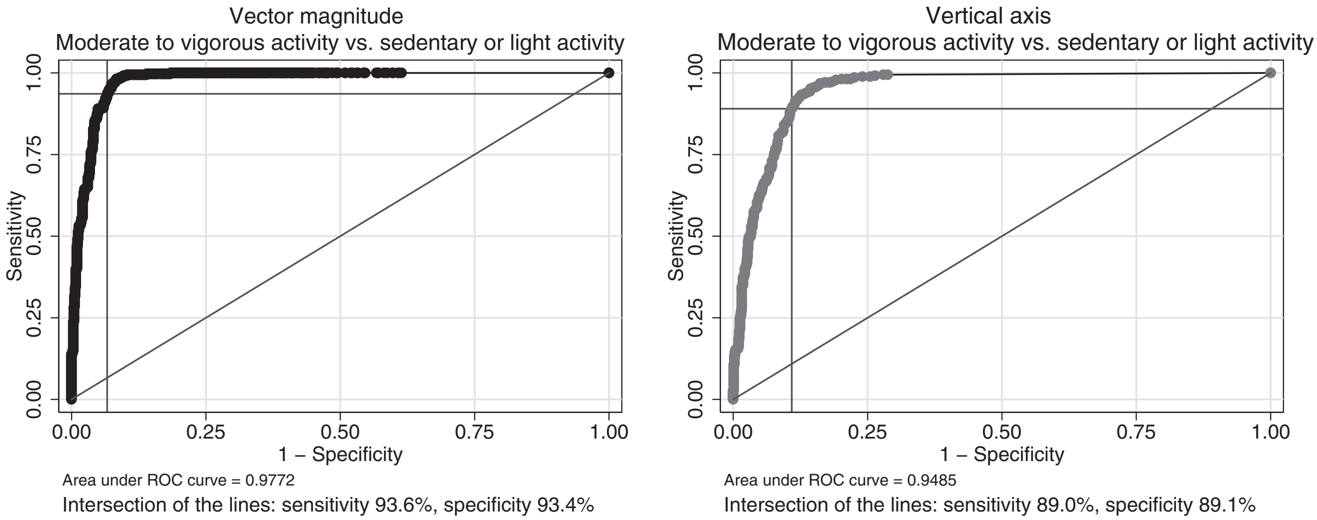

Figure 3 Receiver operating characteristic curves for moderate to vigorous activity versus sedentary to light activity.

Table 2 Cross-classification of observed activity and activity measured by the ActiGraph

	Observation		
	Sedentary/light (%)	MVPA (%)	Total
Vector magnitude			
Sedentary/light (<208)	461 (90.9)	17 (5.8)	478
MVPA (≥208)	46 (9.1)	278 (94.2)	324
Vertical axis			
Sedentary/light (<35)	429 (84.6)	47 (15.9)	476
MVPA (≥35)	74 (15.4)	248 (84.1)	326
Total	507 (100)	295 (100)	

MVPA = moderate to vigorous activity.

DISCUSSION

This study tested the feasibility and validity of the ActiGraph accelerometer by using it to measure physical activity among a sample of 56 Malawian toddlers. The majority of the participants were able to wear the device adequately, and their guardians provided positive feedback on this method of measurement. Accelerometer counts were higher for moderate than light activity, but not for light versus sedentary or vigorous versus moderate activity. In a separate set of observations, cut points of 208 counts/15 sec for vector magnitude and 35 counts/15 sec for the vertical axis showed more than 90% and 80% sensitivity and specificity for separating moderate to vigorous activity from lighter activity.

The study participants were representative of the children in the area when it came to their height, weight and socioeconomic background (17), and they expressed naturally occurring movement patterns with a wide spectrum of activity intensities. Although the participants came from a limited number of villages, there is no reason to believe that they would not be representative of children in the study area. Accelerometer counts were validated against video-recorded direct observation (13), but the relatively low interobserver validity might have decreased the precision of observation. However, only epochs with unambiguous video classification, in other words, only one intensity of activity during the entire epoch, were used in the analysis. Cut points were derived from ROC analysis, a commonly recommended method for validation studies (18,19). Our results therefore support the hypothesis that accelerometer use is a feasible and valid method for measuring physical activity levels among 18-month-old children in rural Malawi.

We were unsuccessful in identifying any earlier publications on the use of accelerometers among children as young as this in Sub-Saharan Africa. However, the findings from the only other formal validation study in this age group, carried out among 20-month-old Belgian children, were very similar to ours (10). There is no reason to believe that children in other settings would be different when it came to accepting the accelerometer device. However, because adults need to put the device on the child, a setting where day care personnel were involved could be different from the Malawian setting. As our study included daily home visits, we cannot be sure that the wear time would be just as good in a setting where there was less frequent contact with study personnel. Other studies carried out with slightly older toddlers or preschool age children in industrialised countries have reported similar activity patterns to those seen in our study and few measurement problems (10,20–22). Therefore, this method seems feasible and valid in a rather wide range of environments and ages.

The cut points separating moderate to vigorous activity from less intensive activity warrant further discussion. In the absence of earlier reports, we could not make any comparisons about cut points for vector magnitude

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obtained with a tri-axial ActiGraph device. Several studies have reported cut points for the vertical axis that are significantly higher than the ones we suggested (21–25). There are several theoretical explanations for this discrepancy, such as the criteria of choosing the cut points from ROC curves and coding the activity intensity based on observation and the size and age and activity patterns of the subjects.

Unfortunately, most studies do not report their exact criteria for the cut points, despite the subjectivity of the ROC method (23,26). As a result, we cannot verify our theory, but we believe that the cut point criteria used by different studies explain part of the differences between our results and other research. We chose to use cut points that show equal sensitivity and specificity and are very close to cut points showing the maximum sum of sensitivity and specificity. It is also possible that using the CPAF observation method contributed to the difference, because it codes any locomotion into moderate activity, while the methods used by other groups typically classify light movement, such as walking, as light activity (27,28). In addition, the CPAF method does not define activity intensities as metabolic equivalents, so it cannot be directly compared with the other observation methods. The effect of age or body size on accelerometer output is unclear, but the fact that children in this sample were shorter than their counterparts in high-income countries may also have contributed to some of the differences (7,29).

In conclusion, waist-worn accelerometry is a valid method of measuring physical activity among toddlers. It can be used for research purposes and possibly clinical practice in Malawi, and it is likely to prove effective when used in other countries. If the method needs to be used to estimate times spent on specific activities, it appears to be most effective in separating moderate to vigorous activity from lighter activity. Because of the wide variations in earlier reports, further work is needed to establish ideal cut points for the various categories of physical activity.

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CONFLICT OF INTEREST

The authors have no conflict of interests.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Figure S1 Receiver operating characteristic (ROC) curves for vector magnitude (VM) and vertical axis (V).

Table S1 Vertical, antero-posterior and medio-lateral axes and vector magnitude accelerometer counts for different observed activity categories.

Table S2 Sensitivity and specificity of different cut points separating moderate to vigorous activity from sedentary to light activity. (a) Vector magnitude accelerometer counts. (b) Vertical axis accelerometer counts.

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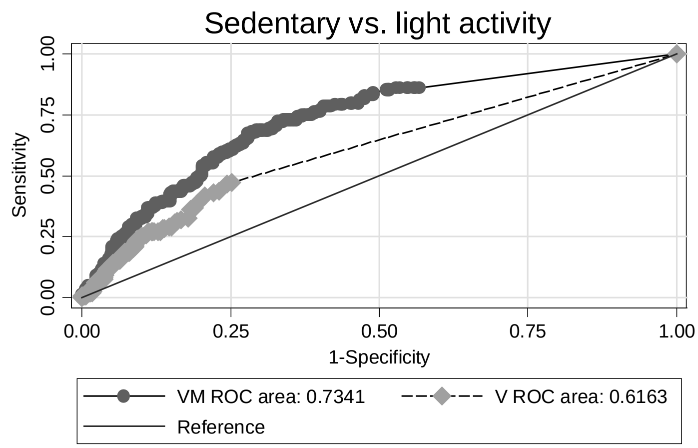
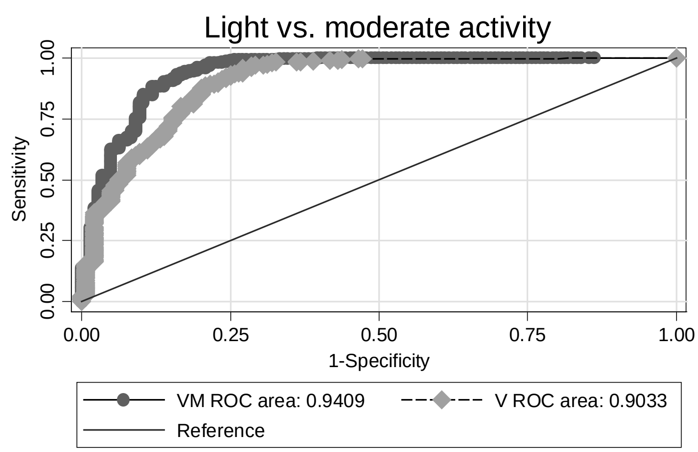
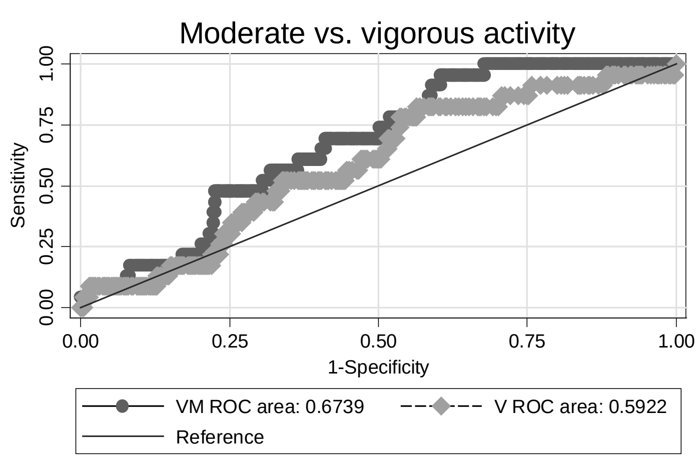
Feasibility and validity of the ActiGraph GT3X accelerometer in measuring physical activity of Malawian toddlers

Figure S1 Receiver Operating Characteristic (ROC) curves for vector magnitude (VM) and vertical axis (V)







Feasibility and validity of the ActiGraph GT3X accelerometer in measuring physical activity of Malawian toddlers

Table S1: Vertical, antero-posterior and medio-lateral axes and vector magnitude accelerometer counts for different observed activity categories.

	Sedentary			**Light**			**Moderate**			**Vigorous**	
	median	IQR	p (sedentary vs. light)	median	IQR	p (light vs. moderate)	median	IQR	p (moderate vs. vigorous)	median	IQR
Vertical axis	0	0 to 1	0.186	0	0 to 25	<0.001	122	56 to 271	<0.001	206	109 to 288
Antero-posterior axis	0	0 to 15	<0.001	40	9 to 85	<0.001	216	148 to 305	<0.001	377	265 to 462
Medio-lateral axis	0	0 to 24	<0.001	32	0 to 84	<0.001	289	172 to 456	0.959	292	254 to 480
Vector magnitude	6	0 to 41	<0.001	58	17 to 146	<0.001	443	294 to 619	0.074	574	424 to 682

Table S2a Sensitivity and specificity of different cut points separating moderate to vigorous activity from sedentary to light activity, vector magnitude accelerometer counts

Cut point	Sensitivity	Specificity	Correctly classified	Sensitivity + specificity
89	100,00 %	81,59 %	87,04 %	181,59 %
110	99,73 %	85,19 %	89,49 %	184,92 %
130	99,47 %	87,77 %	91,23 %	187,24 %
151	98,66 %	90,68 %	93,04 %	189,34 %
166[1]	98,13 %	91,69 %	93,60 %	189,82 %
171	97,33 %	91,81 %	93,44 %	189,14 %
191	95,45 %	92,70 %	93,52 %	188,15 %
201	94,92 %	92,93 %	93,52 %	187,85 %
208[2]	93,58 %	93,38 %	93,44 %	186,96 %
210	93,05 %	93,38 %	93,28 %	186,43 %
232	89,30 %	94,39 %	92,89 %	183,69 %
250	86,10 %	95,40 %	92,65 %	181,50 %
300	75,94 %	96,30 %	90,28 %	172,24 %
350	67,11 %	96,97 %	88,14 %	164,08 %
402	56,95 %	97,98 %	85,85 %	154,93 %
499	43,32 %	98,99 %	82,53 %	142,31 %
600	28,07 %	99,55 %	78,42 %	127,62 %
773	13,90 %	100,00 %	74,55 %	113,90 %

1) highest sum of sensitivity + specificity; 2) equal sensitivity and specificity

Table S2b Sensitivity and specificity of different cut points separating moderate to vigorous activity from sedentary to light activity, vertical axis accelerometer counts

Cut point	Sensitivity	Specificity	Correctly classified	Sensitivity + specificity
0	100,00 %	0,00 %	29,57 %	100,00 %
1	99,47 %	71,27 %	79,60 %	1,7074
5	98,93 %	75,98 %	82,77 %	1,7491
10	97,86 %	80,92 %	85,93 %	1,7878
15	96,79 %	83,84 %	87,67 %	1,8063
20[1]	95,19 %	85,63 %	88,46 %	1,8082
30	90,64 %	88,55 %	89,17 %	1,7919
35[2]	89,04 %	89,11 %	89,09 %	1,7815
40	85,83 %	89,67 %	88,54 %	1,755
50	81,28 %	91,25 %	88,30 %	1,7253
60	72,99 %	92,82 %	86,96 %	1,6581
80	64,17 %	94,61 %	85,61 %	1,5878
100	57,49 %	96,18 %	84,74 %	1,5367
150	44,92 %	97,31 %	81,82 %	1,4223
200	36,90 %	98,20 %	80,08 %	1,351
300	21,66 %	98,77 %	75,97 %	1,2043
400	14,71 %	99,66 %	74,55 %	1,1437
500	9,63 %	99,89 %	73,20 %	1,0952
678	2,67 %	100,00 %	71,23 %	1,0267

1) highest sum of sensitivity + specificity; 2) equal sensitivity and specificity

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ORIGINAL ARTICLE

Effect of 12-month intervention with lipid-based nutrient supplements on physical activity of 18-month-old Malawian children: a randomised, controlled trial

A Pulakka[1], U Ashorn[1], YB Cheung[2,3], KG Dewey[4], K Maleta[5], SA Vosti[6] and P Ashorn[1,7]

BACKGROUND/OBJECTIVES: This study measured the effects of dietary supplementation with lipid-based nutrient supplements (LNSs) on 18-month-old children's physical activity.
SUBJECTS/METHODS: In a randomised, controlled, outcome-assessor blinded trial 1932 six-month-old children from Malawi received one of five interventions daily from 6–18 months of age: 10-g milk-LNS, 20-g milk-LNS, 20-g non-milk-LNS, 40-g milk-LNS or 40-g non-milk-LNS, or received no intervention in the same period (control). The control group received delayed intervention with corn–soy blend from 18–30 months. Physical activity was measured over 1 week by ActiGraph GT3X+ accelerometer at 18 months. Main outcome was mean vector magnitude accelerometer counts/15 s. Analyses were restricted to children with valid accelerometer data on at least 4 days with minimum 6 h of wearing time per day.
RESULTS: Of the 1435 children recruited to this substudy, 1053 provided sufficient data for analysis. The mean (s.d.) vector magnitude accelerometer counts in the total sample were 307 (64). The difference (95% CI) in mean accelerometer counts, compared with the control group, was 8 (−6 to 21, $P=0.258$) in 10-g milk-LNS, 3 (−11 to 17, $P=0.715$) in 20-g milk-LNS, 5 (−8 to 19, $P=0.445$) in 20-g non-milk-LNS, 10 (−3 to 23, $P=0.148$) in 40-g milk-LNS and 2 (−12 to 16, $P=0.760$) in 40-g non-milk-LNS groups.
CONCLUSIONS: Provision of 10–40 g doses of LNS daily for 12 months did not increase physical activity of Malawian toddlers.

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INTRODUCTION

Lipid-based nutrient supplements (LNSs) provide energy, protein, essential fatty acids and multiple micronutrients in a form that has a long shelf life, is palatable and is easy to consume.[1,2] Large-quantity (~200–300 g/day) LNSs, usually designated as ready-to-use therapeutic foods, have proven effective and now form the core of community-based treatment of children with severe acute malnutrition (SAM).[2–5] This success, coupled with other information on LNS properties including acceptability and ease of use, has raised a wide interest to test the applicability of smaller-dose versions (~10–50 g/day) in the promotion of healthy growth.[2] Although there is some evidence that long-term provision of small-dose LNS promotes linear growth and possibly motor development among 6–18-month-old infants in Sub-Saharan Africa, the effect sizes have been rather modest.[6–9]

One possible explanation for a limited growth response to dietary supplementation is a diversion of energy to the child's other needs, such as physical activity. This has been suggested to explain at least part of the difference in weight gain between hospitalised and home-treated children with SAM[10] and it could also occur during dietary supplementation of non-wasted individuals.[11] Because physical activity is an important determinant of young children's cognitive and motor development[12,13] and a contributor to their health in later life,[14,15] it would be important to measure it as an outcome in dietary supplementation trials.

Objective measurement of physical activity has lately become more feasible with the use of accelerometers: small, usually waist-worn motion sensors.[16–18] Because of their low participant burden and ability to record activity over several days, accelerometers are increasingly being used also in paediatric studies.[19,20] Recently, the accelerometers have been validated for use among under-2-year-old children in different settings,[21,22] including a site in rural Malawi,[23] where our research group is testing the health impacts of small-dose LNS provision to infants and young children.[2] In the currently reported study, we measured physical activity with 1-week accelerometer recording among 18-month-old children who had either received no dietary supplementation or 10–40 g of micronutrient fortified LNS per day for 12 months. Child growth was also monitored in this trial, but the results from those analyses will be reported separately. The trial is registered at National Institutes of Health (USA) clinical trial registry with number NCT00945698.

MATERIALS AND METHODS

Setting and participants

This randomised, single-blind, parallel group controlled trial was a substudy under the iLiNS-DOSE trial which was testing the effects of various doses of LNS on child growth. The trial was conducted at two sites in semi-rural Malawi: in the catchment areas of Mangochi District Hospital and Namwera Health Centre. The setting has high prevalence of child stunting but low prevalence of wasting.[24]

[1]University of Tampere School of Medicine, Department for International Health, Tampere, Finland; [2]Duke-National University of Singapore Graduate Medical School, Centre for Quantitative Medicine, Singapore, Singapore; [3]Singapore Clinical Research Institute, Department of Biostatistics, Singapore, Singapore; [4]University of California, Davis, Department of Nutrition, Davis, CA, USA; [5]University of Malawi College of Medicine, Department of Community Health, Blantyre, Malawi; [6]University of California Davis, Department of Agricultural and Resource Economics, Davis, CA, USA and [7]Tampere University Hospital, Department of Paediatrics, Tampere, Finland. Correspondence: A Pulakka, University of Tampere School of Medicine, Department for International Health, 33014 Tampere, Finland.
E-mail: anna.pulakka@uta.fi
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For the main trial, age-eligible children were identified through community surveys and invited to the study clinics for detailed eligibility assessment between November 2009 and May 2011. Eligible children were 5.50–6.49 months old and resided in the study area. Children who were severely ill, wasted, anaemic or allergic to peanuts or other substances, had oedema or were participating in another clinical trial were excluded.

For the physical activity substudy, we recruited all participants who came to the last clinic visit of the main trial at the age of 18 months when they were still receiving the intervention. Those children who had moved out of the study area or whose guardian did not give consent to the substudy were excluded. Data collection was conducted between December 2010 and July 2012.

Randomisation and blinding

A statistician not involved in the data collection created a randomisation list in blocks of 24. On the basis of the list, the research team made randomisation slips containing the letter code of the supplement allocation and sealed the slips in opaque envelopes. A research assistant not participating in the outcome evaluation presented a set of the randomisation envelopes to the guardian of eligible participants. The guardian then chose one of the envelopes. The research assistants measuring activity and anthropometric outcomes were kept blinded to the group allocation until the end of data collection. The researchers doing the analyses were blinded until the data were cleaned and statistical analysis plan finalised.

Trial interventions and participant follow-up

The trial had six study arms: five intervention groups (10, 20 or 40 g of milk-LNS or 20 or 40 g of non-milk-LNS) and a control group. Children in the LNS groups received the intervention from 12–18 months and children in the control group received 71 g of fortified maize/soy flour daily from 18–30 months of age as delayed intervention. The LNS used in this study was produced by Nutriset S.A.S. (Malaunay, France). The nutrient and energy contents of different LNS doses are shown in Supplementary Table 1. A detailed description of the LNS used in this study is published elsewhere.[2,25]

Research assistants home delivered the LNS to the participants every 2 weeks. The participants were followed up at the research clinic every 6 months. The participants in the control group received the same home and clinic follow-ups as children in the LNS groups. Research assistants and nurses provided counselling on infant feeding, including encouragement for breastfeeding, to all the participants' guardians.

Activity measurement

Physical activity was measured over 1 week with the ActiGraph GT3X+ accelerometer (Pensacola, FL, USA), a small, tri-axial, accelerometer weighing 19 g and measuring 4.6 × 3.3 × 1.5 cm. It recorded accelerations in three different axes: vertical, antero-posterior and medio-lateral.[26] We combined the data from these axes as vector magnitude (VM) counts, which we calculated by taking a square root of the sum of squared activity counts of each axis.

During the clinic visit, research assistants instructed the guardians how to secure the accelerometer on the child's right hip using an elastic belt. The guardians were instructed to allow the child to wear the device continuously throughout day and night and remove it only if the child showed signs of discomfort. A research coordinator initialised the accelerometers and a researcher processed the raw accelerometer data using ActiLife software.

Other outcome measurements

Research assistants measured participant's weight in triplicate to the nearest 10 g using an electronic infant weighing scale (SECA 735, Chasmors Ltd., London, UK) and length to the nearest 1 mm using a high-quality length board (Infantometer, Child Growth Foundation, London, UK) at the enrolment to the main trial. We calculated length-for-age *Z*-score (LAZ) and weight-for-length *Z*-score (WLZ) using the WHO 2006 Child Growth Standards.[27] Children's date of birth was obtained from individual health booklets (passports) issued by the health services for recording demographic and health information including immunisations and growth. Research assistants interviewed the guardians to obtain mother's age and education and observed the children to assess their ability to walk. Guardians were also asked whether their children were being carried on five situations (when on the way to the market, fetching water, on the way to the field, visiting neighbours and other) and a score of carrying was constructed by totalling the 'yes' answers. Household food insecurity was measured with Household Food Insecurity Access Scale (HFIAS).[28]

Data processing and analyses

We analysed data using Stata/IC software, version 11.2 (StataCorp, College Station, TX, USA). We used modified intention-to-treat analysis as the basis for analyses. Six participants accidentally received a different group code than intended and they were analysed in the group to which they were erroneously allocated. We set the level of statistical significance at 0.05 for all analyses except for the likelihood ratio test for effect modification where we set it at 0.10.

For physical activity outcomes, we considered data missing if the actual onset of measurement was over 30 days from the planned date. Epoch length was set at 15 s.[16,18,20] We excluded the first and the last day of measurement because they were incomplete days. A day was considered valid if it had a minimum of six hours of accelerometer data between 5:00 am and 8:00 pm, after excluding strings of $\geqslant 20$ min of zeroes. Participants with $\geqslant 4$ valid days of data were included in the analyses. Measurement for 4 days has shown good reliability with children >3 years[20,29] and recently also with toddlers <2 years.[30]

Because of lack of consensus on paediatric cut points for accelerometer data,[17,19] we used mean VM counts/15 s as main outcome. Secondary outcomes included mean vertical axis counts/15 s, % of time spent in moderate-to-vigorous physical activity by VM and % time spent in moderate-to-vigorous physical activity by the vertical axis. We calculated mean VM and vertical axis counts/15 s by averaging mean counts/15 s of each day over all valid days for each of the participants. Percentage of time spent in moderate-to-vigorous physical activity was calculated using validated cut points of 208 counts/15 s for VM[23] and 49 counts/15 s for vertical axis.[22] Mean and % values were used to provide a summary measure of total physical activity over several days, allowing for different lengths of measurement days.

We used Fisher's exact test to test for differences in rate of loss to follow-up between groups. We tested the hypothesis of physical activity of infants in the intervention groups being greater than that of infants in the control group individually for each intervention group and each activity outcome using Student's *t*-test. In addition, the difference in mean activity between all of the groups was tested with analysis-of-variance. We tested interaction between the interventions and seven pre-specified variables (LAZ at 6 months, WLZ at 6 months, sex, season of birth, maternal age, maternal education and HFIAS) with likelihood ratio test, using mean VM counts as the outcome. As a secondary analysis for assessing the relationship between the intervention and mean VM counts, we constructed a regression model, adjusting for the participants' LAZ at 6 months, sex, maternal education, maternal age, and HFIAS. In addition, we built two regression models as a sensitivity test for the latter analysis. The first model included all the co-variables, including effect modifiers and their respective interaction terms. The second one included only those variables that were associated with mean VM counts at $P < 0.1$ level.

The sample size was originally calculated in accordance with the main objective of the trial: 320/group to test a hypothesis of non-inferiority of non-milk-LNS on LAZ as compared with milk-LNS. The sample size of about 180/group for this substudy offered about 80% power to detect an effect size of 0.3 in continuous outcomes at 5% two-sided type I error rate.

Ethics statement

College of Medicine Research and Ethics Committee of University of Malawi and The Regional Ethics Committee of Pirkanmaa Hospital District, Finland reviewed and approved the iLiNS-DOSE trial protocol, including this substudy. Guardians gave a signed or thumb-printed informed consent before the child was enrolled into the main trial and a verbal consent for the substudy on activity measurements.

RESULTS

Of the 1932 iLiNS-DOSE study participants, 451 were lost to follow-up and 79 died before they became 18 months old. An additional 57 declined participation in the activity measurements, thus leaving 1345 (70%) children in this substudy (Figure 1). The background characteristics of enrolled participants were balanced

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between trial groups. The children who participated in the main intervention trial, but were not enrolled in the activity substudy, were otherwise similar to the enrolled ones, except for small differences in maternal education and season of child birth (Table 1).

Of the 1345 participants in the activity measurement substudy, 240 provided insufficient data and 52 otherwise unusable data, leaving 1053 participants in the analyses (55% from the original iLiNS-DOSE cohort). The loss to follow-up rate for groups in this substudy ranged from 20–24%, with no differences between the groups ($P = 0.940$). The mean (s.d.) number of measurement days for the included participants was 5.7 (1.0) and the mean (s.d.) amount of wear-time per accepted day was 11.7 (1.6) hours.

The distribution of physical activity, as expressed by box plots from VM counts, is shown in Figure 2. The mean (s.d.) VM counts for the total sample was 307 (64). The mean values for all physical activity variables are shown in Table 2. For all indicators, children in the control group were slightly less active than children in the five intervention groups. However, the observed differences were small, mostly statistically nonsignificant, and there were no systematic patterns of differences between the intervention groups (Table 2). The only difference that was statistically significant was % of time spent in moderate-to-vigorous physical activity (vertical axis) among infants in the 20-g non-milk-LNS ($P = 0.046$) and 40-g milk-LNS ($P = 0.032$) groups, as compared with controls (Table 2). Adjustment for the participants' LAZ and WLZ at 6 months, sex, season of birth, maternal education, maternal age and HFIAS yielded essentially similar results, that is, no major differences in physical activity between the study groups (details not shown).

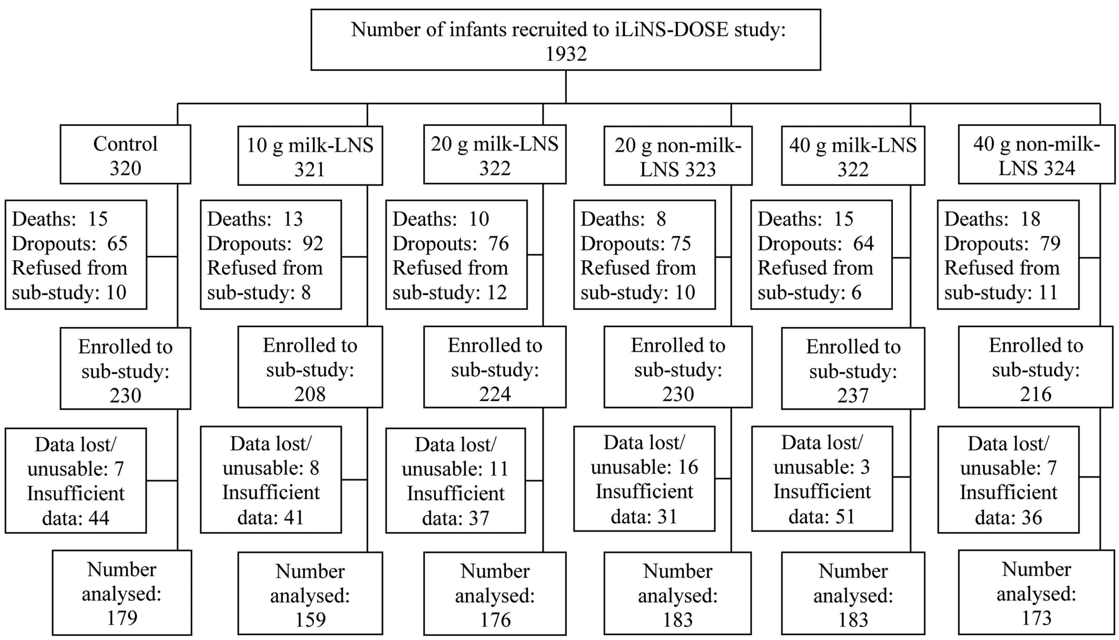

Figure 1. Participant flow.

Table 1. Background characteristics of participants at 6 months and at the time of physical activity measurement

Variable	*Control*	*10-g milk-LNS*	*20-g milk-LNS*	*20-g non-milk-LNS*	*40-g milk-LNS*	*40-g non-milk-LNS*	*Non-enrolled iLiNS-DOSE participants*
Situation at 6 months, main study enrolment							
Number of participants	230	208	224	230	237	216	587
Percentage of males	53	50	51	50	47	51	49
Season of child's birth							
January–March	18%	20%	21%	19%	19%	22%	23%
April–June	18%	16%	17%	18%	19%	16%	22%
July–September	32%	28%	29%	30%	30%	31%	29%
October–December	33%	36%	33%	33%	32%	31%	25%
Mean (s.d.) LAZ	− 1.48 (1.07)	− 1.37 (1.06)	− 1.35 (0.99)	− 1.46 (0.99)	− 1.36 (1.05)	− 1.41 (1.12)	− 1.39 (1.09)
Mean (s.d.) WLZ	0.35 (1.23)	0.25 (1.02)	0.32 (1.16)	0.18 (1.09)	0.21 (1.07)	0.28 (1.10)	0.23 (1.12)
Mean (s.d.) maternal age, years	27 (6.7)	26 (6.4)	26 (6.4)	26 (6.7)	27 (6.4)	26 (5.9)	26 (5.9)
Mean (s.d.) maternal education, completed years of school	4.6 (3.6)	4.5 (3.7)	4.5 (3.6)	4.7 (3.2)	4.2 (3.5)	4.6 (3.5)	5.0 (3.6)
Mean (s.d.) HFIAS	6.5 (6.2)	6.9 (6.2)	6.5 (5.6)	6.9 (6.2)	6.1 (5.6)	6.1 (5.3)	6.6 (6.5)
Situation at 18 months, substudy enrolment							
Mean (s.d.) age at physical activity measurement, months	18.0 (0.41)	18.1 (0.46)	18.0 (0.42)	18.0 (0.44)	18.0 (0.52)	18.0 (0.44)	(N/A)
Walking unassisted	95%	97%	94%	92%	95%	95%	(N/A)
Mean (s.d.) carrying score	2.2 (1.4)	2.5 (1.3)	2.5 (1.3)	2.4 (1.4)	2.4 (1.4)	2.4 (1.4)	(N/A)

Abbreviations: HFIAS, household food insecurity access score; LAZ, length-for-age *Z*-score; LNS, lipid-based nutrient supplement; N/A, not applicable; WLZ, weight-for-length *Z*-score.

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There was an interaction between the intervention and the participants' baseline WLZ on the VM counts at 18 months of age according to the pre-specified significance level of 0.10 for interaction test ($P = 0.079$). Among children whose WLZ at 6 months was above the sample median (0.20), those receiving 20-g milk-LNS, 20-g non-milk-LNS and 40-g milk-LNS were more active than children in the control group, whereas there were no intergroup differences among participants whose WLZ was below median at enrolment (Table 3). There were no significant interactions between the intervention and LAZ at 6 months, sex, season of birth, maternal age, maternal education or HFIAS on physical activity (all P-values >0.10).

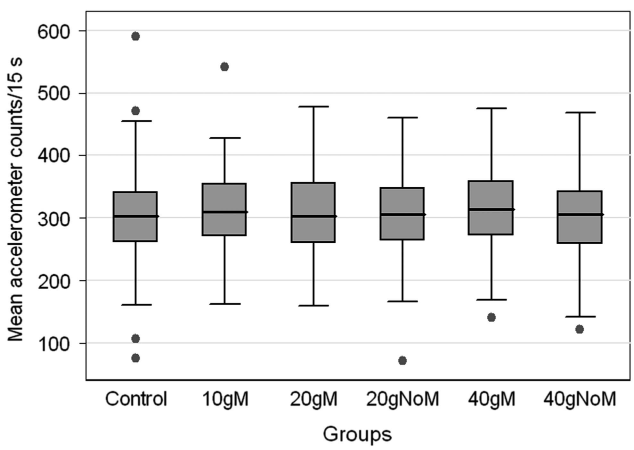

Figure 2. Box-Whisker plots of mean vector magnitude accelerometer counts/15 s by LNS groups. Boxes indicate the upper and lower quartiles of activity counts, lines indicate median counts, whiskers span over data points that are within 1.5 IQR of the nearer quartile, outliers are individually marked. 10 gM, 10-g milk-LNS; 20 gM, 20-g milk-LNS; 20 gNoM, 20-g non-milk-LNS; 40 gM, 40-g milk-LNS; 40-gNoM, 40-g non-milk-LNS.

DISCUSSION

The purpose of this study was to measure the effect of 1-year dietary supplementation with LNS on children's physical activity in semi-rural Malawi. We also tested for interactions between the interventions and several pre-specified variables on physical activity. In our sample, the mean accelerometer counts were slightly higher among the supplemented than the non-supplemented participants, but the differences were small, statistically insignificant, and there was no apparent dose-response in the outcomes. In one subgroup, that is, children whose WLZ-score at enrolment was above the sample median, there was a statistically significant activity difference between the supplemented and non-supplemented participants. Other tested baseline variables did not modify the association between the intervention and physical activity.

The probabilities of bias were minimised in this study with randomised study design and blinding of the outcome assessors. Broad inclusion criteria were used to increase the generalisability of the results. Although loss to follow-up was high, differences in background characteristics between participants who were enrolled or not enrolled into this substudy were small and thus attrition bias is not likely. The sample size was large enough to detect an effect size of 0.3 with about 80% power. The main weakness of the study was that the guardians could not be

Table 2. Physical activity in the trial groups

Variable	Control	10-g milk-LNS	20-g milk-LNS	20-g non-milk-LNS	40-g milk-LNS	40-g non-milk-LNS	P[a]
Mean (s.d.) VM counts/15 s	302 (65)	310 (58)	305 (68)	307 (66)	312 (60)	304 (65)	0.726
Difference (95% CI) between the intervention and the control group		8 (−6 to 21) $P=0.258$	3 (−11 to 17) $P=0.715$	5 (−8 to 19) $P=0.445$	10 (−3 to 23) $P=0.148$	2 (−12 to 16) $P=0.760$	
Mean (s.d.) vertical axis counts/15 s	145 (41)	151 (34)	148 (38)	152 (38)	153 (36)	149 (36)	0.437
Difference (95% CI) between the intervention and the control group		6 (−3 to 14) $P=0.182$	3 (−6 to 11) $P=0.523$	6 (−2 to 15) $P=0.119$	7 (−1 to 15) $P=0.069$	3 (−5 to 12) $P=0.410$	
Mean (s.d.) % of time in MVPA, VM	47.4 (8.9)	48.0 (7.7)	47.2 (9.3)	47.2 (9.7)	48.2 (8.4)	47.1 (9.0)	0.791
Difference (95% CI) between the intervention and the control group		0.6 (−1.2 to 2.4) $P=0.518$	−0.1 (−2.1 to 1.8) $P=0.898$	−0.2 (−2.0 to 1.7) $P=0.870$	0.9 (−0.9 to 2.7) $P=0.340$	−0.3 (−2.1 to 1.6) $P=0.782$	
Mean (s.d.) % of time in MVPA, vertical axis	11.5 (4.4)	12.1 (3.9)	11.9 (4.1)	12.5 (4.3)	12.5 (4.2)	12.0 (4.1)	
Difference (95% CI) between the intervention and the control group		0.6 (−0.3 to 1.5) $P=0.187$	0.4 (−0.5 to 1.3) $P=0.390$	0.9 (0.0 to 1.8) $P=0.046$	1.0 (0.1 to 1.9) $P=0.032$	0.4 (−0.5 to 1.3) $P=0.346$	0.233

Abbreviations: CI, confidence interval; LNS, lipid-based nutrient supplement; MVPA, moderate-to-vigorous physical activity; VM, vector magnitude. [a]P for differences between all groups.

Table 3. Mean vector magnitude counts/15s in the trial groups, stratified by WLZ at enrolment

Variable	Control	10-g milk-LNS	20-g milk-LNS	20-g non-milk-LNS	40-g milk-LNS	40-g non-milk-LNS
WLZ <0.20						
Mean (s.d.) vector magnitude accelerometer counts/15 s	313 (67)	315 (59)	294 (68)	302 (62)	307 (62)	304 (63)
Difference (95% CI) in mean vector magnitude accelerometer counts between the indicated intervention and the control group		2 (−17 to 21) $P=0.828$	−19 (−40 to 2) $P=0.072$	−12 (−31 to 7) $P=0.219$	−7 (−25 to 12) $P=0.482$	−9 (−29 to 10) $P=0.347$
WLZ $\geqslant 0.20$						
Mean (s.d.) vector magnitude accelerometer counts/15 s	290 (61)	303 (57)	312 (68)	313 (71)	317 (58)	304 (68)
Difference (95% CI) in mean vector magnitude accelerometer counts between the indicated intervention and the control group		13 (−5 to 31) $P=0.158$	22 (3–41) $P=0.021$	23 (3 to 42) $P=0.021$	27 (9 to 45) $P=0.003$	14 (−5 to 33) $P=0.150$

Abbreviations: CI, confidence interval; LNS, lipid-based nutrient supplement; WLZ, weight-for-length Z-score.

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blinded to the treatment allocation of their children. However, this is unlikely to have affected the accelerometer measurement. Consequently, we believe that the main results are valid and sufficiently representative of the target population, suggesting that LNS supplementation does not markedly increase the mean physical activity of young children in the defined target group.

The evidence base of using accelerometers in measuring physical activity of toddlers is still evolving. Accelerometers do have some limitations: they are unable to detect upper body movements and they do not provide information on activity type or context.[16,18,20] Furthermore, accelerometer counts need validation before they can be transferred into meaningful units of measurement.[16,19] Outcomes that have been used in studies of toddlers younger than 2 years include time spent in different activity intensities, mean accelerometer counts per minute and % of children meeting activity recommendations.[30–32] Most of the evidence of association between accelerometer-measured physical activity and health outcomes, such as cardiometabolic risk factors,[15,33] body mass index[34] or body composition,[35] comes from children >4 years. Physical activity of toddlers is influenced by many cultural and environment-related variables, such as time spent with other children, physical activity of parents and season of the year.[31,32] How much the child is being carried can also have an impact on the accelerometer readings. The randomised study design did balance the background characteristics between the groups in our sample, but because of the culture-related nature of physical activity predictors, the results cannot be generalised to other settings or age groups.

The observed activity difference among those with above-median weight-for-length could be an indication of some LNS impact in this subpopulation. In the absence of a plausible biological explanation for such an effect modification we, however, consider it more likely to be a spurious observation. This conclusion is, in our mind, also supported by the finding that the calculated activity difference in this subpopulation resulted mostly from lower-than-expected activity counts in the control group, rather than higher counts in the intervention groups.

This was the first study to measure the effects of LNS supplementation on physical activity. Previous studies comparing multiple micronutrient supplements to non-supplementation have used smaller sample sizes and shorter measurement of physical activity and concluded with varying results.[12,36–38] Some studies show increased physical activity of children after receiving multiple micronutrient supplement only[12,38] or with energy.[12,37] A study in Indonesia found that micronutrient supplementation with condensed or skimmed milk increased activity in the cohort of children aged 12–18 months, but not in children aged 18–24 months.[12] A study in Jamaica found that activity increased over time, but it was not associated with the milk-based intervention.[36]

There are several theoretically plausible explanations for this intervention having no significant effect on the measures of child activity reported here. Possibilities include low compliance with consuming the supplement, supplement replacing breast milk intake, extra energy provided by the supplement being used for something other than activity (such as metabolic responses to infections), absorption of nutrients being impaired by infections or children already being as active as might be expected at this age. In our study, the participants even in the control group were at least as active as has been reported for Belgian[21] and Dutch[32] toddlers, although somewhat less active than found for 3–5-year-old children in a recent meta-analysis.[39] That would suggest that the participants of this study, although residing in a food-insecure area, did not have reduced activity compared with their high-income country counterparts. Reported compliance in our study was relatively good[40] and the results indicate that LNS did not replace breast milk,[25] making low compliance or decreased breast milk intake unlikely to explain lack of effect.

Considerable heterogeneity in the results of studies testing LNS for improving growth or treating moderate malnutrition[41] implies that there could be underlying, context-specific mechanisms affecting children's health and well-being and limiting response to nutrition interventions. Energy requirements of children in low-income settings might be higher than in other settings due to repeated infections.[42] Infections and nutrition also interact in ways that are not yet well understood.[43] Thus, interventions to improve children's well-being in low-income settings may need to target multiple risk factors, not just poor nutrition.

In conclusion, our results do not support the hypothesis that LNS, given in 10–40-g quantities per day, increases physical activity among 18-month-old children in semi-rural Malawi, although the intervention may be beneficial to certain subgroups.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Pulakka et al. Effect of 12-month intervention with lipid-based nutrient supplements on physical activity of 18-month-old Malawian children: a randomised, controlled trial

Supplementary Table 1 Nutrient and energy contents of the lipid-based nutrient supplements (LNS)

	10 g milk-LNS	20g milk-LNS	20 g non-milk-LNS	40 g milk-LNS	40 g non-milk-LNS
Daily ration (g)	10	20	20	40	40
Total energy (kcal)	56	118	118	243	243
Protein (g)	1.3	2.6	0.9	5.1	1.8
Fat (g)	4.8	9.6	9.6	19.2	19.1
Linoleic acid (g)	2.2	4.5	4.5	8.9	8.9
α-Linolenic acid (g)	0.29	0.58	0.58	1.17	1.17
Vitamin A (μg RE)	400	400	400	400	400
Vitamin C (mg)	30	30	30	30	30
Vitamin B1(mg)	0.3	0.3	0.3	0.3	0.3
Vitamin B2 (mg)	0.4	0.4	0.4	0.4	0.4
Niacin (mg)	4	4	4	4	4
Folic acid (μg)	80	80	80	80	80
Pantothenic acid (mg)	1.8	1.8	1.8	1.8	1.8
Vitamin B6 (mg)	0.3	0.3	0.3	0.3	0.3
Vitamin B12 (μg)	0.5	0.5	0.5	0.5	0.5
Vitamin D (IU)	200	200	200	200	200
Vitamin E (mg)	6	6	6	6	6
Vitamin K (μg)	30	30	30	30	30
Iron (mg)[1]	6	6	6	6	6
Zinc (mg)	8	8	8	8	8
Copper (mg)	0.34	0.34	0.34	0.34	0.34
Calcium (mg)	280	280	280	280	280
Phosphorus (mg)	190	190	190	190	190
Potassium (mg)	200	200	200	200	200
Magnesium (mg)	40	40	40	40	40
Selenium (μg)	20	20	20	20	20
Iodine (μg)	90	90	90	90	90
Manganese (mg)	1.2	1.2	1.2	1.2	1.2

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Malawian parents' perceptions of physical activity and child development: a qualitative study

A. Pulakka,* P. Ashorn,*† A. Gondwe,*‡ N. Phiri§ and U. Ashorn*

*Department for International Health, University of Tampere School of Medicine, Tampere, Finland
†Department of Paediatrics, Tampere University Hospital, Tampere, Finland
‡iLiNS Project, University of Malawi College of Medicine, Mangochi, Malawi, and
§Department of Community Health, Blantyre, University of Malawi College of Medicine, Blantyre 3, Malawi

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Abstract

Background In scientific studies, physical activity is measured by the amount of bodily movement, but lay perceptions of physical activity might be different. Parental influence is important for the development of children's physical activity behaviour, and parental perceptions of facilitators of physical activity are context specific. We aimed to investigate how parents of young Malawian children conceptualize physical activity in childhood, situate it in child development and understand its facilitators.

Methods We used convenience sampling to identify parents of young children from different socio-economic backgrounds and age groups in semi-rural area of Malawi. We conducted in-depth interviews with 16 parents, a focus group discussion with six parents and key informant interviews with two nurses in Malawi. Six of the participants were fathers. We analysed the data with conventional qualitative content analysis by inductive approach.

Results The parents emphasized practical skills, education and proper behaviour as goals for their children. They viewed activity as encompassing both mental and physical qualities and they perceived it as a positive attribute of children. The parents discussed skills acquisition, social competence, health and bodily movement as signs for being active. As facilitators of physical activity the parents mentioned balanced diet, good health and stimulation. The main concerns of the parents in regard to facilitators of physical activity and good child development were the availability of food and the child being healthy.

Conclusions Malawian parents' concept of children's physical activity is more comprehensive than scientific definition and includes aspects of both physical and mental activity.

Keywords
development, physical activity, preschool children, qualitative study, sub-Saharan Africa

Correspondence:
Anna Pulakka,
Department for International Health,
University of Tampere School of Medicine,
Lääkärinkatu 1, 33014
University of Tampere,
Finland
E-mail: anna.pulakka@uta.fi

Introduction

Studies testing interventions for improving child health or nutrition in low-income settings have used physical activity as one of the outcomes (Gardner *et al.* 1995; Jahari *et al.* 2000; Aburto *et al.* 2010; Pulakka *et al.* 2014). Apart from the beneficial health effects (Ekelund *et al.* 2012; Timmons *et al.* 2012), physical activity in young children is a determinant of good motor, cognitive and social development (Jahari *et al.* 2000; Burdette & Whitaker 2005; Timmons *et al.* 2007). Children develop physical activity behaviour at home under parental influence (Loprinzi & Trost 2010; Pocock *et al.* 2010; Dowda *et al.* 2011), but how parents value physical activity can be associated with their child-rearing goals. A universal goal of child rearing is to provide children with skills that help them to function adaptively in their communities and become competent members of their social group (Kagitcibasi 2004; Tamis-LeMonda *et al.* 2008).

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In the scientific literature and health promotion practice, physical activity has often been defined as any bodily movement produced by the skeletal muscles that raise energy expenditure above resting values (U.S. Department of Health and Human Services *et al.* 1996). Physical activity of children can be measured both by subjective methods (i.e. self-reports) and objective methods (e.g. observation or accelerometers that measure acceleration generated by bodily movement; Oliver *et al.* 2007; Trost 2007). In low-income countries, children's physical activity has been assessed by observation (Gardner *et al.* 1995; Aburto *et al.* 2010), and more recently, by accelerometers (Faurholt-Jepsen *et al.* 2014; Pulakka *et al.* 2014). The outcomes used in physical activity studies include, for example, duration and intensity of movement (Cliff *et al.* 2009; Matthews *et al.* 2012). However, the definition of physical activity and the outcomes used may be differently understood by lay people. Understanding lay perceptions is important in developing culturally appropriate measurement tools (Gladstone *et al.* 2008, 2010; Hallal *et al.* 2012). This could help the community to interpret health information as well as scientists to disseminate their study results in a way that is meaningful to lay people (Popay & Williams 1996; Allmark & Tod 2006).

Parental views on physical activity of young children have recently been studied in high-income countries (Irwin *et al.* 2005; Dwyer *et al.* 2008; Hinkley *et al.* 2011; Hesketh *et al.* 2012; De Craemer *et al.* 2013), but studies from low-income settings are scarce. Because perceptions of physical activity can be context specific, research on parental perceptions of children's physical activity in low-income settings would add understanding of factors that affect child health. In this study, we explored Malawian parents' perceptions of children's physical activity and development. We sought to investigate how parents of young Malawian children conceptualize physical activity in childhood, situate it in child development and understand its facilitators. We used qualitative interviews because they are applicable for exploring the different meanings people give to health and factors that affect health (Baum 1995).

Methods

Setting and participants

The study was carried out in semi-rural Mangochi district, Southern region of Malawi. Mangochi district has high child mortality and prevalence of chronic undernutrition. In 2010, under-five mortality was estimated at 136/1000, prevalence of stunting at 48%, literacy rate for women at 52% and for men at 74% and total fertility rate at 7.0 (National Statistical Office Malawi & ICF Macro 2011). The houses in the area are generally small, with one-third of people living in houses occupied by more than three persons per room, and only 2% of the houses have electricity (National Statistical Office Malawi 2012). Children spend much of their day outdoors playing with or being cared by other children.

We used convenience sampling to identify parents of young children from different socio-economic backgrounds and age groups. We confined the respondents to parents because their attitudes and behaviour can impact children's physical activity (Hinkley *et al.* 2008) and because through their personal experience they could be considered as experts in child rearing. To increase the comprehensiveness of data, we also interviewed two key informants who had deep knowledge on the culture and child health in the study area through their long careers as a nurse. The interviews were under ongoing iLiNS-DOSE trial, which was reviewed and approved by the College of Medicine Research and Ethics Committee of the University of Malawi. All the participants gave informed verbal consent that was tape recorded.

Interviews and analysis

The data were collected with in-depth interviews (IDIs) and a focus group discussion (FGD). IDIs were continued until no new issues emerged, i.e. saturation was reached. IDIs and FGD were chosen over observational methods because we aimed to understand respondents' beliefs and attitudes rather than analyse their actual behaviour. We organized one FGD for practical reasons. However, respondents appeared to express themselves more freely in individual discussions; thus, the subsequent data were collected by IDIs. All the interviews and the FGD were voice recorded. A female health scientist with a 'Western' background, who spent about half a year in Malawi (AP), carried out the FGD, key informant interviews and seven IDIs in English. A trained Malawian female research assistant conducted eight IDIs in a local language, Chichewa, and translated them into English. The persons who conducted the IDIs and the FGD transcribed them verbatim.

We used an interview guide with mostly open-ended questions in both the IDIs and the FGDs. The questions for subsequent interviews were modified during the data collection and preliminary analysis, but the main themes remained the same. In addition to some background questions, themes of the interviews covered signs of physical activity and good development (e.g. 'what are the signs that show you that your child is active/developing well?') as well as facilitators of activity and development (e.g. 'what makes child to be active?'). We also asked about

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Table 1. Background characteristics of the participating parents

	Individual/pair interviews	Focus group discussion
Number of persons	16	6
Number of males	4	2
Mean age (range)	29 (20–47)	29 (26–31)
Mean number of children (range)	2.4 (1–8)	1.8 (1–2)
Mean age of the youngest child (range)	3 years (6 months to 7 years)	5 years (3–8 years)
Occupation	Data collector: 3	Driver: 2
	Health surveillance assistant: 3	MSCE level: 2
	Housewife: 3	Secretary: 1
	Cleaner: 1	Teacher: 1
	Data monitor: 1	
	Data clerk: 1	
	Guard: 1	
	Land scraper/gardener: 1	
	Meter reader: 1	
	Nanny: 1	
Number of illiterate participants (%)	2 (13%)	0 (0%)

MSCE, Malawi School Certificate of Education (secondary school certificate).

the parental expectations about their children's future (e.g. 'what would you like your child to do when she is 15 years old/adult?') and issues that children should learn. When conducting the interviews, we specifically used two words that were identified through discussions with Chichewa-speaking research staff to describe physical activity: *kuchangamuka* and *kutakataka* (e.g. 'what kind of child is ochangamuka/otakataka?'). According to a recent Chichewa/Chinyanja–English dictionary, *kuchangamuka* can be translated as being alert, on your guard, active, get/wake up, watch out, be brisk or be brave. *Kutakataka* is translated as to move, to move about, be busy at work, do business, to wriggle or be free to move (Paas 2013).

We analysed the IDIs and the FGD with conventional qualitative content analysis (Graneheim & Lundman 2004; Hsieh & Shannon 2005) with inductive approach. Preliminary data analysis started alongside with the data collection. A researcher (AP) read through the IDIs and the FGD transcripts several times and coded for the emerging meaning units. She then grouped the codes into categories and formulated the categories further into themes that included the same, underlying meaning. As peer debriefing, and to benefit from both insider and outsider view, the researcher discussed the findings both with colleagues with in-depth insight on Malawian culture (AG and NP) and with the research assistant who conducted part of the interviews.

Results

Background information of the participants

We conducted 15 IDIs, one FGD and two key informant interviews between October 2010 and February 2013. None of the approached people declined the interview, but one IDI was excluded from the analyses because the interviewee was not a parent. Two of the interviews were paired, i.e. had two interviewees present at the same time, making the total number of included IDI respondents 16. Mean age of the parents was 29 years and two of them were illiterate (Table 1). Two of the IDI respondents were participants in the iLiNS-DOSE trial. The IDIs lasted from 12 to 39 min, with the mean duration of 23 min. The FGD lasted for 35 min and the key informant interviews 30 and 40 min.

Parents' concepts about physical activity and child development

Being physically active was seen as a positive attribute of a child and as a sign of being normal and healthy. According to both the parents and the key informants, the two vernacular words that we used for physical activity, *kuchangamuka* and *kutakataka*, referred both to physical and mental activity, i.e. activity in the way how the children moved about and activity in thinking.

> An active (*wotakataka*) child is always energetic and is intelligent and when you send him/her to do something he is very quick. When you send the child to get plates, he/she goes and gets plates, and if you send the child to go and play ball, the child will do that. (Father, 47 years, IDI in Chichewa)

> If the child is active (*wochangamuka*), definitely it means that the child also grows fast because even the way the child thinks shows that. And sometimes there are two kids of the same age but the one who is active will think through in more matured way than the other one.

> Sometimes you can also differentiate and see that the younger child is thinking in a more clever way than the older one if the younger one is active. (Mother, 28 years, IDI in Chichewa)

The parents described a physically active child as one who learns new skills early, is smart, behaves well, plays with friends, is healthy and moves around. We grouped the activity-related factors into four main categories: skills acquisition, social competence, health and movement (Table 2). The attributes that the parents gave for well-developing children could largely be grouped in the same main categories as attributes for physical activity, with the exception of movement (Table 2).

In regard to skills acquisition, the parents perceived active children as the ones who learned skills early compared with other children and had good cognitive skills, which was marked by good memory and performing well at school. As to social competence, parents mentioned active children having good behaviour, playing with friends and not being afraid of new situations. An example that the parents recurrently used was that the children were quick in fetching things when asked to. In regard to health, the parents explained that active children were not often sick and had strong and energetic body. The parents also perceived children who moved around much, e.g. by running, jumping and climbing trees, to be physically active.

As opposite to active children, the parents described quiet or passive children who would just sit still or stay in one place for long periods of time without going to play with their friends. Inactive children could also be too shy or fearful in a new environment and cry when their mother is leaving. Inactivity would cause the parents to worry that the children were either sick or having problems with their development. According to the parents, lack of activity could reflect on children's future behaviour so that they would become lazy and have bad behaviour.

Generally, the parents thought that their children were physically active but they wanted the children to become even more active. However, there were also some contrasting arguments, as

Table 2. Signs of physical activity and development

Signs of child being active	Signs of good development	Subcategory	Category
Learns motor skills (crawling, sitting, standing) Learns to talk, asks questions Plays with balls, mud, tins Imitates others	Learns skills (e.g. motor skills, talking, household chores) Imitates others Does not lose skills that he/she already had	Practical skills	Skills acquisition
Is clever, intelligent, wise Has good memory Performs well at school	Has growing wisdom Starts remembering things Performs well at school	Cognitive skills	
Learns motor skills early Does things better than children of the same age	Learns skills early Does things as an older child even at young age	Timing of skills	
Is quick in doing what is asked/expected (e.g. fetches things, greets visitors) Does not do what is forbidden	Learns to know people, remember their names Goes to fetch things when asked	Good behaviour	Social competence
Plays with friends Is leader of a group	Interacts with other children Imitates others	Interaction with peers	
Does not cry when sees mother leaving Has courage to do tasks independently Is not fearful outside home	Is happy Is curious, has a mentality of discoveries Is not quiet	State of mind	
Is healthy, not often sick	Is healthy, not often sick Has growing health	Physical health	Health
Has strong, active and energetic body	Has increasing body size Has strong, smooth, active or well-structured body Is not looking malnourished (body is not weak or thin)	Appearance of the body	
	Has good and increasing appetite Eats many kinds of foods Is not refusing to breastfeed	Appetite	
Runs, jumps, climbs trees Touches things 'Does this and that' Does not stay still		Moving around/motion	Movement

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some of the parents mentioned that too much physical activity can be seen as uncontrollable, abnormal or problematic. According to these parents, children could be doing mischiefs or troubling their friends if they were too active.

> Yeah, they [the children who are too active] are not controlled by the parents. So, it's not . . . it becomes a level whereby you start also [to] complain: no, this is now too much. (Father, 30 years, FGD in English)

When asked about activity of girls and boys, both the parents and the key informants said that girls are generally expected to be less active. Some of the parents explained that a too active girl might be considered to be mixing too easily with other people which might lead to prostitution. This was more of a concern in regard to older children than toddlers. However, some of the parents expressed satisfaction on the fact that their girls were very active.

Being active was well in line with the goals that parents set for their children. As short-term goals, the parents wanted their children to learn basic skills of taking care of themselves and carrying out household chores (Table 3). On a longer term the parents placed importance on schooling and proper behaviour. School attendance was seen as a way forward to a profession, which in turn would both increase independence of the children and enable them to support the parents. The parents emphasized, however, that the children can make their own choices about the profession. One of the important goals was that the children should become well-behave, respectful and polite, especially towards elders.

Perceived facilitators of activity and development

The parents discussed facilitators of physical activity under three themes: balanced diet, good health and stimulation (Table 4). The main concerns of the parents were the availability of food and the child being healthy. According to them, food would make the child's body strong and being frequently sick would prevent the child from being active. As regard to stimulation, parents

Table 3. Children's developmental goals described by the parents

Expressed goals	Category	Example of quote
Eating and drinking Going to the toilet Not wetting bed Putting on clothes Avoiding dangerous issues Brushing teeth Finding food Moving around	Independent care of basic needs	*Okay, he has to learn to do things by himself, maybe to put on his clothes when there is nobody at home (. . .)Maybe if he tries to take a bath by himself, so maybe if I'm not around, he can do . . . Maybe brushing his teeth by himself.* (Mother, 27 years, IDI in English)
Fetching water Washing dishes Sweeping the ground Cooking *nsima* (maize-based staple food) Preparing tea Cleaning the house Fetching water Carrying things on the head Growing vegetables Carpentry Repairing radios	Learning household chores	*The important thing a boy needs to learn is everything that you have, you as parents tell them to do. Yeah. Like tell them to go to school, teach them sweep the ground, how to clean the plates, yes. How to clean on their home, house. Yes. And our country needs a person who knows how to garden vegetables in the field.* (Father, 29 years, IDI in English)
Getting a profession (such as nurse, doctor, teacher, police, craft worker or mechanic) Being able to support parents	Becoming educated	*I want my child to be an educated person who has gone through school. (. . .)When a person is educated s/he has an advantage [or something to lean on]. Because in addition to the qualification that he/she has, he/she can also manage to find some piece work to do.* (Mother, 20 years, IDI in Chichewa)
Respecting others, especially older people Being polite Not using bad language Not bringing shame to parents Not stealing Not doing prostitution Observing faith by going to church and fearing god.	Having proper behaviour	*Respect of other people. Mainly the elders, the parents, the elders. Umm . . . as they are growing, they are . . . they have to teach them, they have to learn to respect.* (Father, 30 years, FGD in English)

FGD, focus group discussion; IDI, in-depth interview.

Table 4. Facilitators and barriers of activity and good development (barriers are marked in *italic*)

Facilitators and barriers for activity	Facilitators and barriers for good development	Category	Example of quotes
Enough food Frequent meals Balanced diet Specific foods: nsima†, phala†, fruits	Enough food Frequent meals Food from different food groups Age appropriate food (breast milk for infants) Specific foods: nsima†, phala†, enriched with ground nut powder, soya or margarine, green vegetables and fruits *Ignorance of parents on what to feed to the child*	Balanced diet	*Because of this, when the food that the child eats makes the child's body strong because of the food that you are giving to the child (. . .)What makes a child not to be active is that if the child eats less and less important food.* (Mother, 41 years, IDI in Chichewa)
Being healthy	Not being frequently ill Taking the child to the hospital when needed *Frequent illnesses, such as malaria or diarrhoea* *Improper sexual behaviour of the parents*	Health	*. . . and also diseases, because it the child gets sick often, the body of the child turns not to be physically active.* (Father, 47 years, IDI in Chichewa)
Playing with friends Going to (nursery) school Toys, television, bicycle Playing with ball Good behaviour of parents Parents showing example by being busy *Carrying the child* *Leaving the child with a maid*	Interacting with parents, siblings, other children and grandparents Playing with friends Going to (nursery) school Toys, television, bicycle *Lack of time of the parents to be with the child* *Playing with children of bad behaviour*	Stimulation	*They need to have toys that they can play with. Umm . . . for the toys it's, either you can buy for them or you can use these local things. Like this wire you can [make] something [for] them to play with or you can use these plastic [bags] and make a ball for a child so that she can be active.* (Mother, 27 years, IDI in English)
	Bathing every day Having clean clothes Clean surroundings of the house Having soap *Not washing the child* *Not changing clothes*	Cleanliness	*For my child to grow well she needs soap for bathing and washing clothes. She needs good clothes, a good place to sleep, eating good food so the child grows well.* (Mother, 41 years, IDI in Chichewa)

†Nsima and phala: local, maize-based porridge.
IDI, in-depth interview.

mentioned that children should be allowed to play with other children and use equipment such as balls or toys to be active.

As facilitators of development, parents listed similar issues as those of physical activity, with an additional category of cleanliness (Table 4). A recurrently mentioned concern was again food, which the parents discussed in regard to adequate amounts, sufficient variety and appropriateness for the age of the child. The parents viewed poverty as a barrier to good child development, especially in reference to inability to buy appropriate food. Being infrequently sick and being taken to the hospital when needed were mentioned as facilitators of good development. When talking about cleanliness, the parents considered being bathed often and wearing clean clothes as beneficial for development. Although parents saw fulfilment of basic needs as pivotal for child development, after some probing, they also mentioned issues of stimulation, such as interaction with other people, as necessary for development.

> For my child to grow up well she needs to be eating from all the food groups, and also the clothes are cared for. But also when she is ill you should rush to the hospital. (Mother, 31 years, IDI in Chichewa)

Discussion

The aim of this study was to explore how parents of young Malawian children conceptualize physical activity in childhood, understand its facilitators and situate it in child development. The interviewed parents perceived practical skills, education and good behaviour as goals for their children. They viewed physical activity as activity of both the mind and the body and they considered it mainly to be a positive attribute of a child. According to the parents, physically active children were learning new skills early, socially competent, healthy and moving around much. As facilitators of physical activity, parents mentioned balanced diet, good health and stimulation.

The strengths of this study include varied background of the interviewed parents and use of a local language in some of the IDIs. The reliability of the results was increased by data saturation, triangulation of data sources, i.e. by including both parents and key informants, and peer debriefing. Using language that was not native for the respondents, as well as using translated text in the analysis, confined us to the analysis methods that do

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not require language fluency (Bernard & Ryan 2010). The sample was slightly biased towards more educated parents than average Malawians as only two participants were illiterate. Two of the IDI respondents were taking part in a trial with activity measurements for the children, but this was unlikely to influence their perceptions of activity as the measurements were performed after the IDIs. Taking into account these issues when interpreting the results, we do believe that the results represent the view of the parents in this area of Malawi.

We were unable to identify studies from low-income countries about parental perceptions of young children's physical activity. Our results suggest some similarities and differences with studies performed in high-income countries. As facilitators of activity, issues related to stimulation, such as parental example, having friends and siblings, attending pre-school and having access to sports equipment, are congruent with views of parents in North America, Australia and Europe (Irwin *et al.* 2005; Dwyer *et al.* 2008; Hinkley *et al.* 2011; Hesketh *et al.* 2012; De Craemer *et al.* 2013). Parents in these high-income countries viewed safety concerns, poor access to play areas, extreme weather, children's preference of television viewing and high cost of organized activities as barriers to physical activity (Irwin *et al.* 2005; Dwyer *et al.* 2008; Pocock *et al.* 2010; Hinkley *et al.* 2011; Hesketh *et al.* 2012; De Craemer *et al.* 2013), none of which was mentioned by the Malawian parents. In contrast, parents in the aforementioned studies did not discuss adequate nutrition or good health as facilitators of activity.

The scientific definition of physical activity as bodily movement produced by the skeletal muscles is very different from the perceptions of the parents in our study who viewed bodily movement only as part of the more comprehensive concept of physical activity. The parents' perception of activity as a mostly positive attribute of the child, including skills acquisition, social competence, health and bodily movement, actually depicts some of the possible beneficial associations between physical activity and motor, cognitive or social development that have been found in previous studies (Jahari *et al.* 2000; Burdette & Whitaker 2005; Timmons *et al.* 2007). The difference between the scientific definition and parents' perception emphasizes proper cultural adaptation of self-report measurement tools of physical activity, which are still widely used in low- and middle-income countries (Hallal *et al.* 2012). Caution should also be used when disseminating results obtained with objective methods, such as recently validated accelerometers (Pulakka *et al.* 2013), in a way that is understandable to lay people.

The finding that parents place importance in the fulfilment of children's basic needs as a facilitator of child development is in concordance with other studies from low-income settings. For example, Gusii parents in Kenya prioritized child survival and health (LeVine *et al.* 1998) and immigrant mothers in Italy placed great emphasis on health and nutrition of their children (Moscardino *et al.* 2006; Moscardino & Bonichini 2007). Although the ongoing nutrient intervention trial in the area might have increased respondents' emphasis on nutrition, the concern of sufficient food was expressed by respondents both involved in the trial and not. As Malawi has high child mortality and nutritional problems are common but access to outdoor play is easy, it is logical that parents place emphasis on good nutrition and health.

We conclude that the parents and the key informants in this study viewed activity as a positive attribute, encompassing both mental and physical features and being well in line with the development goals for children. The parents focused mostly on fulfilment of basic needs when describing facilitators of physical activity but they also mentioned stimulating environment. Researchers and public health practitioners should be aware of the meanings that parents give to physical activity. In this case, parents viewed physical activity more comprehensively than what is measured in research studies.

Key messages

- Malawian parents considered physical activity as both mental and physical character and mainly as a positive attribute of a child. According to them, an active child learned new skills early and quickly, was smart, behaved well, played with friends, was healthy and moved around.
- Being active was well in line with the goals that parents set for their children, which, in a short term, were to learn basic skills and carrying out household chores and in a longer term to attend school and have proper behaviour.
- Parents placed emphasis on balanced diet and good health as facilitators for physical activity but they also mentioned stimulation, such as playing with friends.

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Conflict of interests

The authors declare no conflict of interest.

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