Preface

This PhD thesis was conducted at the Faculty of Health Sciences, Institute of Regional Health Research and at Centre of Research in Childhood Health, Department of Sport Science and Clinical Biomechanics, University of Southern Denmark, in the period 2011 – 2014.

This thesis presents results obtained from The Childhood Health, Activity and Motor Performance School Study, Denmark – The CHAMPS Study-DK. In 2007 the city council of the municipality of Svendborg, Denmark, decided to create sports schools with the intention to improve physical health of children (the Svendborg Project). The CHAMPS Study-DK was made responsible for the scientific evaluation of this project. The study is ongoing since August 2008 and has the overall aim to investigate the effect of additional physical education on children's health in a school based curriculum. The studies of this thesis focus on the importance of childhood motor performance on future physical activity level and on the risk of musculoskeletal extremity injuries in children. The author of this thesis contributed to the data collection for the studies in the period august 2011 to June 2013.

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List of papers

This thesis is based on the following three papers, referred to by their roman numerals in the text:

I. Lisbeth Runge Larsen, Martin G Jørgensen, Tina Junge, Birgit Juul-Kristensen and Niels Wedderkopp: **Field assessment of balance in 10 to 14 year old children, reproducibility and validity of the Nintendo Wii board** *BMC Pediatrics, 2014, 14:144 doi:10.1186/1471-2431-14-144*

II. Lisbeth Runge Larsen, Peter Lund Kristensen, Tina Junge, Birgit Juul-Kristensen Niels Wedderkopp: **Motor performance and balance as predictor of lower extremity injuries in children – The CHAMPS Study-DK** *Submitted for Sports Medicine, December 21st 2014*

III. Lisbeth Runge Larsen, Peter Lund Kristensen, Tina Junge, Christina Trifanov Rexen, Niels Wedderkopp: **Motor performance as predictor of physical activity in children - The CHAMPS Study-DK** *Accepted for publication December 9th 2014 in Medicine & Science in Sports & Exercise*

Thesis at a glance

Paper	Objectives & Participants	Methods	Conclusions
I	1) To investigate reproducibility of the Nintendo Wii Board (NWB) and a laboratory force platform (AMTI) in a field setting 2) To explore the concurrent validity of the NWB when compared to the AMTI in a field setting, testing bilateral and unilateral balance in a random selection of children and adolescents. 54 participants, 45% boys, 10-14 year-olds	Four different static balance tests (sway), both bilateral stance and unilateral stance. Three rounds of the four tests were completed with the NWB and with the AMTI. To assess reproducibility, an intra-day test-retest design was applied with a two-hour break between sessions.	Both NWB and AMTI have satisfactory reproducibility for testing static balance in a population of children. Concurrent validity of NWB when compared to AMTI was satisfactory. This study suggests, that NWB is a reproducible and valid tool for measuring sway of children in a field setting
II	To examine, whether motor performance tests, including tests of postural sway, can predict lower extremity injuries, overuse as well as traumatic injuries, in a normal population of children across several sports types 1244 participants from 8-14 years old	Motor performance tests SMS-track (automated text messages) with reports on musculoskeletal complaints and leisure time sports participation Telephone consultation identifying injuries and diagnosed by ICD-10 Anthropometric measurements	Sway performance was a consistent predictor of traumatic injury in children, in particular traumatic injury of the ankle region. Good performance in single leg hop for distance significantly protected against traumatic injury. Good performance in core stability and shuttle run increased the risk of overuse injuries in the knee region.
III	To explore the longitudinal relationship between motor performance and physical activity in a three-year follow-up study. 673 participants (44% boys, 6-12 years old)	Motor performance tests Accelerometer measurements Anthropometric measurements	Several motor performance tests were longitudinally associated with physical activity (PA) in children. Better performance in the shuttle run, cardio respiratory fitness, vertical jump and handgrip increased the PA level. In particular, it seemed to be important with good performance in cardiorespiratory fitness and the shuttle run in childhood, and perhaps the skills are most important for boys.

Description of contributions

	Study design	Data collection	Data analysis	Manuscript writing	Manuscript revision
Paper I	LR, NW, BJK	LR	LR, NW, BJK	LR	MGJ, BJK, NW, TJ
Paper II	LR, NW	LR, TJ, KD, CTR, HK, NCM	LR, PLK,	LR	PLK, NW, TJ, CTR
Paper III	LR, NW	LR, TJ, KD, SF,	LR, PLK, NW	LR	PLK, NW, TJ, BJK

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Abbreviations

AMTI: AMTI force platform

BMI: Body Mass Index

CCC: Concordance Correlation Coefficient

CHAMPS Study-DK: The Childhood Health Activity and Motor Performance School study – Denmark

COP: Centre Of Pressure

COPL: Centre Of Pressure path Length

FMP: Fitness related aspect of Motor Performance

ICC: Intraclass Correlation Coefficient

IRR: Incidence Rate Ratio

LOA: Limits Of Agreement

MDC: Minimal Detectable Change

Mean MVPA: Mean percentage of time in Moderate to Vigorous Physical Activity

NWB: Nintendo Wii Board

PA: Physical Activity

SD: Standard Deviation

SEM: Standard Error of the Measurement

Introduction

The current thesis will examine the longitudinal associations between

1) The motor performance level in children and their risk of injuries in the lower extremities
2) The motor performance level in children and their physical activity level

This introduction will give a short description of the key terms. Definitions of motor performance will be described, as will the existing knowledge on the relations known so far between childhood motor performance, and future physical activity and physical activity related injuries in children respectively.

Motivating children towards a healthy lifestyle is an important goal to encourage a healthy lifestyle later in life. Identifying the underlying factors associated to a physically active life, and factors associated to injury prevention in childhood, could be some of the steps towards promoting a healthy lifestyle and well-being in children. The hypotheses investigated in this thesis are, that our motor competences could be some of several possible factors associated to the level of physical activity in a long-term perspective, and to the risk of physical activity related injuries. In children the motor competences are often addressed as "fundamental movement skills", motor skills" or "motor performance"(1-6).

Motor performance

The definitions of motor performance, fundamental movement skills and motor skills seem to differ (4-6). Furthermore, the definition of motor performance as a single concept varies. Motor performance has been defined as "*the act of executing a movement skill*" (6), which means it differs from motor skills defined as *"the underlying process of gaining control in voluntary movement of the body, limbs and/ or head (6)"*. Or motor performance can be defined as a part of overall physical fitness and as an umbrella term of, and in close relationship with, motor skills, strength, power and motor control (5).

In this thesis motor performance, fundamental movement skills and motor skills are considered to be closely related, and it is anticipated that motor skills and fundamental movement skills are antecedent skills to achieve good motor performance. Tests of motor skills, fundamental movement skills and motor performance can be product-oriented or process-oriented (6). Product-oriented tests measure the outcome of a skill e.g. jumping height, and generally, motor performance items are often measured by product-oriented tests as for example how fast you run (seconds), how high you jump (centimetre) or how well you perform a balance task (e.g. centimetre measuring centre of pressure path length (COPL) in a static standing position) (5, 6). The process-oriented tests measure the pattern of a performance such as the mechanics and sequences of a movement (6), which are, in this thesis, anticipated to relate to primarily motor skills. Measures of fundamental movement skills are anticipated to include both product-oriented and process-oriented tests. In this thesis product-oriented tests are anticipated to relate primarily to motor performance.

Relation between motor performance and physical activity

Motivation to physical activity is related to our competences in moving and to the perception of competences to move (7). The competences to move, reflected in e.g. motor performance, is important to children and adolescents` physical, psychological and social development, and may be the foundation of an active lifestyle (4, 6, 7). Thus, it is hypothesized, that a good motor performance is correlated to physical activity (PA). This hypothesis is supported by cross sectional studies showing positive associations between motor performance or fundamental movement skills and PA (3, 4, 8, 9), and by studies concluding that sufficient motor performance is required to develop sport specific skills and to experience success in movement activities which might influence the physical activity level (9, 10).

A recent review including studies of children aged 3 to 16 years old, examined the health related benefits of motor performance. The review suggested that motor performance was positively associated to PA level, cardiorespiratory fitness and inversely associated to weight status (4). The articles included in the review used both product and process oriented tests, and the suggestions were made from primarily cross sectional studies, as only two of the 21 included articles were longitudinal. This may indicate, that the motivation to participate in leisure time sports, or to be physically active in general, might be significantly influenced by the skill level of motor performance. In particular, developing good motor skills and motor performance in early childhood, where the learning potential is high, is anticipated to be important for the continued interest in PA as children grow and become increasingly aware of their own abilities. In other words, inadequate motor performance could result in a reduction of the PA level. Supportive of this hypothesis is a cross sectional study describing the characteristics of children with low levels of motor skills that showed strong and consistent associations between low skill level, an inadequate cardiorespiratory fitness and low levels of PA (11). However, as only two of the studies in the review by Lubans et al. (4) were longitudinal, the longitudinal relationship between motor performance and PA still seems undetermined.

The few other identified studies, which have examined the longitudinal relationship, have looked at different components of motor performance or related aspects, as motor skills (1, 12) or a single component such as cardiorespiratory fitness (13, 14). The measure of PA in these studies was either self-report (1, 12, 14), or the PA level was only examined in relation to cardiorespiratory fitness (13). Measuring PA in children by self-report might lead to information bias (1, 12, 14). This is probably due to incorrect recall of PA amount, difficulties in quantifying the intensity and the need of help to answer from parents or other adults, resulting in subjective responses on PA registrations.

Consequently questionnaires on PA behaviour tend to have low validity when used in child populations (15, 16).

The lack of longitudinal studies of the relation between motor performance and PA, has led to several studies calling for investigation of the longitudinal association between motor performance and PA from childhood through adolescence, especially longitudinal studies using objective measures of both PA and motor performance (4, 9, 17, 18).

Physical activity in relation to health

Physical activity is associated with numerous health benefits in children and protection from lifestyle diseases (19-22), e.g. physical activity is an important factor for metabolic health in children, as physical activity prevents clustering of cardiovascular risk factors in children (23). Furthermore, reviews found evidence for associations between several psychological and social health benefits of PA, e.g. including mental well-being, higher self-esteem and social skills, self-efficacy, perceived activity competence, goal orientation, motivation, and sports participation (22, 24, 25).

In the course of adolescence a decline in the amount of physical activity has been reported (26, 27), showing that physical activity level decreases from 9-15 year olds, especially around 15 year olds and most obviously among boys (28, 29). Inconsistencies exist, whether the physical activity curve decreases from the age 12-13 years old or 13-14 years old (28, 30, 31).

Physical activity has a tendency to track from childhood to adulthood, the most physically active individuals continued to be so (32, 33), and the level of tracking might be stronger than earlier stated due to new, more reliable objective measures of PA (32). This highlights the importance of studying potential determinants of PA during childhood in order to facilitate good habits for physical activity in childhood and to support factors and behaviour positively associated to physical activity. Establishing good PA habits might be essential to encourage children to become more physically active through adolescence. Following the above reasoning, the time span between 9-15 years of age, and probably also earlier years up till the decrease in PA appears, seems to be a period in which possible explanatory factors can be identified.

In summary, motor performance could positively influence the PA level, and as PA is important in relation to risk of e.g. cardiovascular disease and type II diabetes (19-23, 34), this could benefit personal and public health.

A drawback of physical activity is the risk of related musculoskeletal injuries, both in adults and children. Physical activity related injuries have been established as a leading cause of paediatric injuries in western countries (35-38), this generates the question of how to prevent physical activity related injuries.

Injuries in children

Physical activity related injuries constitute an important and costly public health matter in terms of both direct and indirect costs for children and parents (39).

Physical activity related injuries are mostly defined by one of three criteria: 1) any physical complaint regardless of the need for medical attention or time loss from activity, 2) physical complaint receiving medical attention or 3) a complaint resulting in time loss from activity (40).

Previously, the use of the "need for medical attention criteria" has led to the fact that registration of injuries in children primarily included acute injuries due to registration at emergency departments or consultations by medical doctors (36, 38). A recent Swedish study presenting an overview of injuries in children and youth, reported contusions, open wounds, fractures and sprains to be the four most frequent reported injury categories (38). In a Danish context it was reported that, apart from bruises and contusions, distortions are the most common injury type in children aged 10 to 14 years old, and the foot region to be the most common site of injury (41). But the majority of the previous studies have aimed to assess traumatic injuries, suggesting that the studies should not have stated or reported that "the most common injuries were contusions, open wounds, fractures and sprains" but rather that the "most common traumatic injuries are contusions, open wounds, fractures and sprains". The ability to register all types of complaints from children by using Short Messaging Service-Track questionnaire (SMS-Track), on cell phones to send a short questionnaire concerning musculoskeletal complaints (42), has given the opportunity to register complaints by the use of the "any physical complaint criteria" (40). Using complaint as an indication of an injury, leading to further clinical examination, has lead to the possibility of a more detailed and comprehensive registration of injuries in children. Including both acute injuries and overuse injuries. E.g. in a Danish study, the SMS-Track was used as the underlying method to collect information on incidence and prevalence of physical activity related injuries among 6 to 12 year old children by data from The Childhood Health Activity and Motor Performance School study – Denmark (the CHAMPS Study-DK) (42, 43). This method showed that approximately one third of injuries in children were traumatic, two thirds were overuse injuries (43). The location of the overuse injuries was mainly in the lower extremity (94.5%). Furthermore, the lower extremity is one of the most common regions to sustain traumatic injuries (41). This underlines the need of knowledge on how to identify the children at risk of sustaining an injury in the lower extremity, overuse as well as traumatic.

Injury types and the relation to health

Injury mechanisms differ between traumatic and overuse injuries. Traumatic injuries are those resulting from a single, specific, and identifiable event whereas overuse injuries are caused by repeated micro trauma without a single, identifiable event responsible for the injury (40). The pathological condition of overuse injuries in children and adults differs, though, due to the immature skeleton in children. Whereas overuse injuries in adults often represents as tendinopathy in e.g. the Patella tendon or the Achilles tendon, in children the result of the repeated micro trauma often affect the physes, either the epiphyses or the apophyses (44). Where the epiphyses are pressure growth plates situated in the long bones and contribute to longitudinal growth, the apophyses are traction growth plates located at the site of attachment of major muscle tendons to bone (44). The apophyses are 2 -5 times weaker than the surrounding fibrous tissue in children which leads to injuries situated in the physes, as apophysitis, as these are the weak spot (44). The apophyses are subjected to tensile forces and contribute to bone shape but not the longitudinal growth. Even though apophysitis, e.g. Osgood-Schlatter lesion, Sinding-Larsen_Johansson lesion or Severs lesion (45), does not affect bone growth by leading to disturbances in the longitudinal growth, it has been shown to be an injury to the active remodelling bones comparable to a stress fracture or epiphysiolysis (46). Thus, apophysitis could lead to sever traumatic injury or long-term consequences, as seen e.g. in Osgood-Schlatter lesion where there is a risk of avulsion fracture or development of painful ossicles in the fibrous tissue close to the tuberositas tibiae (44). Furthermore, traumatic as well as overuse injuries are painful for the children and may lead to cessation in physical activity level and / or sports participation.

The pain and discomfort accompanying physical activity related injuries in children often leads to immediate reduced physical activity and not rarely absence from school and/or sport, because of short-term disability (47). Traumatic injuries may also have long-term consequences such as osteoarthritis and limited physical activity later in life, and loss of enthusiasm for participating in physical activities (47-50). In a recent review of the literature on injury prevention in childhood and youth (51), several long-term consequences were reported too. E.g. 50% of children / adolescent with meniscal or anterior crucial ligament injury was reported to suffer from osteoarthritis 10 to 20 years after the diagnosis (52). Furthermore, around 16% of patients who had reconstructed the anterior cruciate ligament reported to have rigorously modified their lifestyle 11 years after operation (53). Regarding ankle sprains in youth (13 to 20 years old), 74% reported pain, swelling, weakness or perceived instability 2.5 years after the injury, and 16% did not return to their sport (54).

In elite child athletes it has been reported, that the amount of overuse injuries seems to increase, maybe as a result of increased frequency and intensity in the training schedules in child and adolescent sports (55, 56) forcing parents and health professionals to balance the beneficial effects of sports with the injury risk (55, 57). Thus, from both an individual and a public health point of view, it is important to try to identify risk factors and establish injury prevention strategies in childhood, to avoid the negative long-term consequences, as these are substantial.

Establishing the aetiology of physical activity related injuries in children precedes a preventive intervention as illustrated in the model by van Mechelen et al. (figure 1) (58). The aetiology of physical activity related injuries is suggested to be a complex interrelationship between intrinsic risk factors (dependent of the individual), extrinsic risk factors (environmental dependent,) (59, 60), non-modifiable risk factors (e.g. gender or age) (61, 62) or modifiable risk factors of injury (e.g. physical fatigue (63), decreased proprioception (64)). Several risk factors for injuries in child populations have been identified (64, 65), and the knowledge of intrinsic modifiable risk factors, e.g. motor performance measures (66, 67), can help identify the children at risk and probably generate ideas for interventions to protect children against injuries.
The above reasoning highlights the importance of defining risk factors for both traumatic and overuse injuries in children in order to develop preventive interventions.

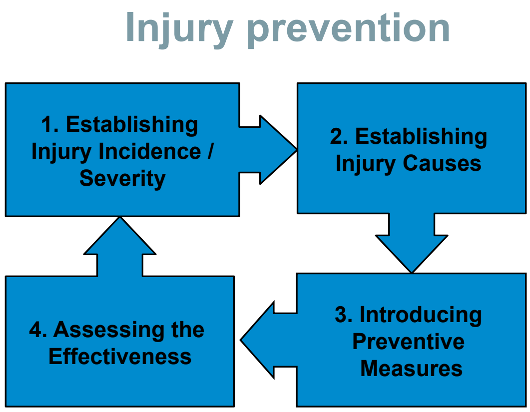


Figure 1 A four stage model of injury prevention (58)

Relation between motor performance and injuries
Inconsistency exists about the influence of motor performance on injury risk (63, 64, 68-72). Tests of motor performance had an inverse relationship to risk of traumatic injury in some studies indicating good cardio-respiratory fitness, strength and good neuromuscular control to be preventive of injuries (64, 68-70). Other studies found a positive relationship suggesting good skills in agility, acceleration and soccer increased injury risk (in soccer players and American football players) (70, 73), whereas others found no significant relation between motor performance tests and risk of injury (63, 71, 72). However, the majority of these studies examined adolescents older than 15 years old or young adults, and none of the identified studies examined motor performance as predictor of injuries included children younger than 13 years old.

In adults, one of the more consistent findings is the relation between different measures of balance and the risk of injury in the lower extremities, especially ankle distortions (64, 69, 74-78). When balance is measured as sway performance on a force platform, decreased balance is concluded to be an intrinsic risk factor of traumatic ankle injury and re-injury among adults (76, 79-81). The majority of studies included less than 50 participants, but we identified two longitudinal studies examining the influence of several fitness components on risk of injuries, that measured balance by force platform (69, 77). The studies had 241 male participants (69) and 159 female participants respectively (77). All the participants were young adults and the studies did not find sway measures to be predictive of ankle injuries.

The use of a force platform to assess static, standing balance (sway), as COPL excursions, or Centre Of Pressure (COP) velocity, is frequent in laboratory settings (82-86) but not in field settings, probably due to high prices of equipment and sensitive set-up of equipment. The force platform technique to measure sway can provide clinicians and researchers with a valuable 'bio-signature' similar to that seen in gait analyses and potentially capable of predicting injuries or fall accidents (76, 79-81, 87). A force platform measures three-dimensional forces, the anterior-posterior, the medio-lateral and the vertical forces. If a person is standing still, balance can be measured as sway including only the anterior-posterior and medio-lateral forces (88). This type of quantification of balance has been shown possible to measure on a Nintendo Wii Board (NWB) in adult populations (85).

Sway in children differs from sway in adults because the centre of mass is located relatively higher in children compared to adults. This leads to differences in the magnitude and velocity of sway, children swaying at a faster rate than adults (temporal, spatial and continuous refinements of postural strategies) (89-92). The sway in children reaches adult levels at 12-15 years of age, but refinements of the balance strategies probably continue through adolescence (89). The reliability and validity of the NWB has not been investigated in child populations. If the NWB is reliable and valid to measure sway in children, it opens for measures of sway in large populations, and maybe to include sway measures as a field measure.

Reflecting balance as a measure of sway reduces the information on the total concept of balance from a functional perspective, as it is a measure of postural control when standing still on a non-moving base. But as balance is an important ability during normal daily activities regardless of one´s age (76, 79-81, 87, 92), an objective measure of balance, e.g. measured as sway, does complement the measure of motor performance. To our knowledge, sway has not been examined as a risk factor for physical activity related injuries in large populations of children.

Summary of introduction

In summary, only few studies investigating relations between motor performance and injury risk have been identified, and these were sport specific and only included acute injuries (63, 70, 72). Thus, the knowledge of motor performance tests and balance ability as risk factors of injuries in children is inconclusive and sparse, especially regarding overuse injuries in the lower extremities (65). As the direction of the examined associations differed, it is still not clear whether high skill level in motor performance tests protects against injuries or increases injury risk. Furthermore, the relation between sway measures and risk of injuries has not been examined in a large population of children, but in adults poor balance increases injury risk (76, 79-81). To include a sway test, as a field test of balance, requires equipment presenting satisfying reliability and satisfying concurrent validity when used in child populations outside laboratory settings.

Cross sectional studies have reported motor performance to be significantly positively associated to physical activity in children, but only few longitudinal studies were conducted, and these often only examined one or few components of motor performance (13, 14) or they used self reported measure of PA (1, 12, 14) which might affect the validity of the PA measures (15, 16). Thus, there is a need for longitudinal studies with objective measures of PA and motor performance.

Aim and objectives of the thesis

Aim

To achieve more knowledge on the longitudinal relationships between motor performance and injury risk, and motor performance and physical activity level, in Danish school children.

Objectives

1) To investigate the reproducibility of the Nintendo Wii Board to measure balance as sway in a population of children aged 10 to 14 years old, and to investigate the concurrent validity of the Nintendo Wii Board to measure sway in a population of children aged 10 to 14 years old, when compared to a force platform (Paper I)
2) To investigate motor performance, including sway, as predictor of traumatic and overuse injuries in the lower extremities, in children aged 9 to 14 years old at baseline, in a 15 months follow-up study (Paper II)
3) To investigate longitudinal associations between motor performance and physical activity in children aged 6 to 12 years old at baseline, in a three years follow-up study (Paper III)

Methods

The current study is a sub-study of The CHAMPS Study-DK (42). The CHAMPS Study-DK is an on-going longitudinal cohort study initiated in August 2008. The study is situated in the municipality of Svendborg, in the southern part of Denmark.

All 19 public schools in the municipality of Svendborg were invited to participate in the CHAMPS Study-DK. Six of these schools agreed to become a sports school. The municipality was asked to provide six matched control schools, but only four schools agreed to become a control school. As a result, the participants attending 10 public schools were included. In the control schools the number of physical education (PE) lessons followed the ordinary curriculum offering two hours of PE lessons per week. In the six schools addressed as sports schools they offered six PE lessons per week. Sports schools and control schools were matched based on school size and uptake area and socio-economic position of the parents. Thus The CHAMPS Study-DK is not a randomized controlled study, but a quasi-experimental study, conducted as a natural experiment. Sample size calculation have been described in detail previously (42).

All children and parents from kindergarten to 4^{th} grade were asked to participate in the research program. At baseline in 2008, the CHAMPS Study-DK invited 1507 students to participate in the research program (42), 90% from the sports schools agreed to participate, 71% from the control schools agreed to participate resulting in 1218 participants.

As the CHAMPS Study-DK is an open cohort, the number of participants varies through the years, thus the number of participants varies in the papers of the current thesis.

Study population

Reproducibility and concurrent validity study (Paper I)

The participants in the study for paper 1, examining the reliability and concurrent validity of the NWB when compared to the laboratory force platform (AMTI), were recruited from one school participating in the CHAMPS-Study DK. A random sample of 58 participants from the fourth, fifth and seventh grade (aged 10-14 years old) agreed to participate. Exclusion criteria were severe leg and back injuries or pain that would prevent the child from standing on one leg, illness (i.e. fever) during the last week, neurological disease and one or more missing follow-up measurements.

Motor performance as predictor of injuries (Paper II)

This study had 1246 participants (aged 8-14 years old) at baseline in March 2012. Beside motor performance data and complete diagnostic specification, the inclusion criterion was 80% compliance in the SMS-Track. Participants were followed for up to 15 months.

Longitudinal associations between motor performance and physical activity (Paper III)

At baseline in September 2009, 1213 participants (aged 6-12 years old) took part in the CHAMPS Study-DK of which 1146 participants had baseline data on both motor performance and anthropometrics. Participants were followed for three consecutive years.

Measurement of motor performance

Tests of motor performance, motor skills and fundamental movement skills can be process – or product oriented as mentioned above. As this thesis focuses on motor performance and not motor skills, the measures of motor performance are product oriented in nature, and the quality of the movements performed during the tests was not rated. The measures of motor performance will be addressed as the fitness related aspects of motor performance (FMP) reflected in quantitative measures as e.g. measures of cardiorespiratory fitness, jumping height and seconds to finish the shuttle run. The tests of FMP will include measures of static strength, power, dynamic strength, jumping tasks, throwing tasks, balance and different running tests reflecting either agility or cardiovascular fitness as defined by Malina et al (5).

For most of the FMP tests there is no gold standard, which makes it difficult to establish the concurrent validity of these tests. However, handgrip has in systematic reviews been found relatively valid to express upper body muscular strength (93, 94) and in a sub-study of the CHAMPS Study – DK, the Andersen test has been found valid to estimate cardiorespiratory fitness in children (95). The vertical jump test has been found reliable (96), and a single study found the test relatively valid to measure lower body muscular strength in youth (94). However, in a recent systematic review examining the validity of field tests, the validity of vertical jump was not concluded upon due to very few studies examining the validity of this test in a child population (93, 94). Balance is defined as the ability to control the centre of mass within the base of support (92). As postural control includes both balance and postural orientation (92), postural control is inherently linked to balance ability. Different tests in test batteries measure balance as a composite of motor coordination tasks, such as backwards balance on different balance beams (97, 98) one legged balance in seconds and different hopping tests as a trial to quantify balance with differing scoring systems (99, 100). But the quantification lacks the objective specification of the quality of the balance tasks due to scoring on ordinal scales. Quantification of balance in quiet stance is possible on a force platform (88) as measures of sway, expressed as COP excursions by the COPL. COP is defined as the position of the global ground reaction force vector that accommodates the sway of the body, also expressed as the point in which the centre of mass transmits from the body to the base (88, 92, 101). The length and velocity of COP is closely related to postural stability, or balance, and thus also postural control, as a good stability requires an ability to maintain the centre of mass within the base of support (92). The longer fluctuations in the centre of mass, the less stable a person is. Thus, when measuring sway, a short COPL per time unit is equivalent to a good postural control and good balance. Outcome measures obtained with a force platform are objective and previously considered a 'gold standard' for assessing standing balance (102), as this method is capable of quantifying subtle changes, that are otherwise difficult to quantify using subjective outcomes (87).

Motor Performance data

A trained team performed the FMP tests of the participants. The clinicians performing the tests were thoroughly instructed in all test procedures during two full days of practice that included standardized calibration of the equipment, and measurement and instruction procedures. The first day the clinicians practiced on each other, the second day the tests and procedures were tested on a child population aged as the participants in the CHAMPS Study-DK.

The tests were performed in school sports halls, and participants were tested with their classmates during a physical education lesson. Tests of motor performance consisted of

1. Vertical jump test corresponding to Abalakow's vertical jump test (103). Best of three trials. If third jump performance was highest, participants continued trials until levelling off. This is a proxy for lower body muscular strength in youth (93, 94) measured as jumping height in cm.
2. Short shuttle run test from the Eurofit test battery (104). Participants should run five laps on a 5m lane. This is a measure of agility, measured in seconds.
3. Prone bridge. Participants kept prone static position on elbows and toes until fatigue. This is a measure of static core stability, measured in seconds.
4. Side bridge. Participants kept side bridge position on elbow and feet until fatigue. This is a measure of static core stability, measured in seconds.
5. Single leg hop for distance on the dominant and non-dominant leg. Participants jumped as far as possible on one leg. Best of three trials was recorded (or until the subject made no longer progress). This is a measure of functional capacity (105), measured in cm.
6. Andersen test. A test of cardiorespiratory fitness, valid for this age group (95). It is an intermittent running test, laps on a 20m lane for ten minutes, measured in meters.
7. Backward balance. A balance test from the Körperkoordinations Test fur Kinder" (97, 98). The participants walked backwards on three different balance beams (6, 4.5 and 3cm wide), with three trials on each beam: Counted as number of successful footsteps with a maximum of 8 points per trial. Possible scores ranged from 0-72 points

8. Precision throw from “Der Allgemeiner Sportmotorischer Test für Kinder von 6–11 Jahren” (106). The participants were standing three meters from a target plate, each participant had two times five throws. Possible scores ranged from 0-3 point per throw, making it possible to get up to 30 points.
9. Handgrip strength from the Eurofit test battery (104). Measured in kg (JAMAR dynamometer, Scandidact, Cat.No.281128). The better of two trials was recorded.
10. Balance, measured as sway on Nintendo Wii board. Postural sway was measured by the four following static balance tests: (1) Bilateral stance with eyes open, (2) unilateral stance with eyes open on the dominant and (3) non-dominant leg, and (4) bilateral stance with eyes closed. The dominant leg was defined as the leg for ball kicking. Sway was registered as Centre of Pressure path Length (COPL) in cm. The median of the three COPL measures from three successful trials in each of the four different tests was chosen for analysis. Shorter COPL was interpreted as superior to longer COPL, then the shorter the COPL, the better balance the participant was supposed to have.

The Andersen test and handgrip has been shown to be valid in child populations (93-95, 107). Intraclass Correlation Coefficients (ICC) of test-retest reliability for the FMP tests handgrip, vertical jump, precision throw, backwards balance and short shuttle run ranged between 0.81-0.98 (107). Test-retest reliability of the prone bridge test and side bridge test were examined in pilot projects resulting in ICC ranging from 0.92-1.00 (108)

The NWB has been shown to be a useable, reliable and valid tool to measure sway in adult populations. This thesis aimed to examine the validity and reliability of NWB in a population of children (Paper I). The four sway tests were selected on the basis of their varying difficulty, suitability for the age group and common use (84, 85, 109). Duration of each trial was 30 seconds, in line with previous studies (84, 85, 110, 111). Specification of the data registration and download are described in Paper 1.

In paper II baseline FMP scores were divided into health-related fitness and performance-related fitness according to previous studies (112, 113). Handgrip and the Andersen test were categorized as health-related measures. Vertical jump, shuttle run, backward balance and precision throw were categorized as performance-related measures.

Anthropometrics

Information on age, pubertal stage and BMI were collected during the FMP test rounds.

- Weight was measured to the nearest 0.1 kg on an electronic scale, (Tanita BWB-800S, Tanita Corporation, Tokyo, Japan) wearing light clothes.

- Height was measured to the nearest 0.5 cm using a portable stadiometer (SECA 214, Seca Corporation, Hanover, MD).
- Pubertal stage was assessed by Tanner self-assessment questionnaire (114, 115). For the analyses in paper II pubertal stage was dichotomized (Tanner stage 1= pre pubertal, Tanner stage 2-5=pubertal). In paper III pubertal stages were treated as a categorical variable (Tanner stage 1= pre pubertal, Tanner stage 2, 3 & 4=pubertal, 5=finished puberty).

Parental educational level was obtained as baseline information collected by a questionnaire when participants entered the project.

Registration of injuries

The physical activity related injuries in the current thesis were defined as "any physical complaint regardless of the need for medical attention or time loss from activity".

Complaints

This first indication of an injury was the report of complaints from the parents to the participating children measured by weekly Short Messaging Service-Track questionnaire (SMS-track) version 2.1 (New Agenda Solutions, SMS-Track ApS, Esbjerg, Denmark). To indicate complaints, the parents were asked:

"Has (the child's name) during the last week had any pain?" with possible answers of

1=neck, back or low back;

2= shoulder, arm or hand;

3= hip, leg or foot; or

4=no, my child has not had any pain.

The answers of the SMS-track were sent once a week (Sundays) and automatically put into a database. The input was checked for nonsense values (e.g. o instead of 0 or a text instead of a number), and in these cases, the parents were contacted to get a correct answer. To improve compliance, a reminding text message was sent to the parents if no answer was registered within 72 hours and 120 hours. The mean answer rate by SMS-track was 97%.

Injury data

In case of complaints, a telephone interview with the parents was performed, to identify children in need for further physical examination. Physiotherapists and chiropractors examined and diagnosed the children in a mobile clinic visiting each school once every 14 days. The injuries were registered by use of the ICD-10 system for diagnostic specifications. The injuries were collected from 1st of April 2012 until 30th of June 2013.

All injuries from the knee and ankle regions were included in the analyses of Paper III, in addition to total number of injuries in the lower extremity. Hip and groin injuries were not examined as a unique group due to a very small sample.

Measurement of physical activity

Physical activity in this thesis is defined in the broad sense as "*any bodily movement produced by skeletal muscles that result in energy expenditure*" (116).

Measurement of physical activity level in children is challenging due to PA patterns characterized as sporadic and intermittent in nature, consisting of short high-level bouts of activity (15, 117), often lasting less than 15 seconds (117, 118). These activity bouts are not caught by questionnaires on PA in children. Thus, it is preferable to measure PA in children by an objective measurement tool, as accelerometers, in intervals no longer than 15 seconds (117, 119). Objective measures by accelerometers allows for registrations of PA in intervals of e.g. 2 seconds. The Actigraph detects acceleration along the vertical axis, corresponding to differences in levels of intensity and energy consumption (15) and has been found both to be a reliable and valid tool for measuring PA level in children (15). In the current thesis, PA was measured by uniaxial accelerometry using the Actigraph GT3X (Pensacola, Florida, USA).

Participants were asked to wear the Actigraph for 7 consecutive days during waking hours, and not to wear the device during water activities. The Actigraph was worn in an elastic belt around the hips, placed on the right side.

In order to clean the data for non-physiologic values and to sort out inactivity periods due to non-wear of the device, data was screened in a customized software program (Propero, version 1.0.18, University of Southern Denmark, Odense, Denmark). Periods with consecutive strings of "0" for 30 minutes or longer were classified as non-wear time. Further, participants with less than ten hours of registration per day were excluded, as this threshold is commonly accepted to represent "a normal day" (32, 120). Only participants with a minimum of four accepted days were included in the analysis (121, 122).

PA was expressed as moderate to vigorous physical activity, generated by cut-points according to Evenson et al. (15). Differences in total wear-time of the Actigraph were taken into account by using the mean percentage of time in moderate to vigorous physical activity (mean MVPA) per day. In order to control for day type variation in physical activity, weekend activity was weighted by 2/7 and weekday activity by 5/7.

Sport participation

The SMS-Track was also used to collect data on sport participation. To account for individual exposure time in Paper II, we included the individual sports participation rate per week. Sports participation was measured as sports participation per week. To indicate the amount of sports participation the parents were asked:

“How many times did (the childs name) engage in sports during the last week?”

with possible answers of

0=none,

1=once,

2=twice,

3=three times,

…… or 8=more than 7 times.

Ethics

All children and parents from the participating schools retrieved information about the study through school meetings and by written information. Written informed consent was obtained from the parents of the participants. Participation in the study was voluntary at all times, with the possibility to withdraw from the entire project or parts of the project. Furthermore, during the collection of FMP data, it was possible to withdraw from one or more tests or anthropometric measurements.

Ethical approval was obtained from The Regional Scientific Ethical Committee of Southern Denmark as part of the CHAMPS-Study DK (project ID S-20080047). The CHAMPS-Study DK conforms with the declaration of Helsinki (123).

Statistics

Statistic analyses

An overview of primary exposures and outcomes, statistical methods and adjustment of possible confounders in the three papers is given in table 1.

All calculations and statistical analysis were conducted in STATA (version 13.0 or version 13.1) (Statacorp, College Station, Texas, USA). Significance level was set at $p \leq 0.05$.

Table 1 Overview of the chosen primary exposures and outcomes, statistical methods and potential confounders

Paper I		
	Outcome	Median of three trials
	Quantification of reproducibility and validity	Bland Altman plots with 95% LOA
	Quantification of intrasubject variability	SEM and MDC
	Coefficients of reproducibility and validity	Concordance Correlation Coefficient
	Interpretation of CCC	CCC>0.70 = satisfying
Paper II	Primary exposure	FMP tests
	Primary outcome	- Traumatic injuries of lower limbs - Traumatic injuries in the knee region - Traumatic injuries in the ankle region - Overuse injuries of lower limbs - Overuse injuries in the knee region - Overuse injuries in the foot region
	Descriptive statistics	Means (SD), medians
	Longitudinal analyses	The zero-inflated negative binomial model, the zero-inflated Poisson regression, the Poisson regression or the negative binomial regression depending on the best model fit of the data
	Potential confounders	Previous injury, sports participation, age, school type, body mass index (BMI), pubertal stage and gender
Paper III	Primary exposure	FMP tests
	Primary outcome	mean percentage of time in moderate to vigorous physical activity (Mean MVPA per day)
	Descriptive statistics	Means (SD), medians, comparison of descriptive data between genders by T-Test or Wilcoxon rank-sum test
	Longitudinal analysis	Multilevel mixed effects linear regression models
	Potential confounders	Mean MVPA, sex, age, BMI, parental educational level, puberty, type of school

Reliability and concurrent validity study (Paper I)

The primary outcome used for the analysis of reproducibility and concurrent validity was the median of the three COPL measures from three successful trials in each of the four different tests. The median was chosen as it was used in a similar study (85), but also to eliminate possible outliers. To quantify reproducibility of the measurement devices and the concurrent validity, Bland-Altman plots with 95% limits of agreement (LOA) were calculated (124). The 95% LOA visualizes the spread of the current measurements. Further, the Bland-Altman plots with the 95% LOA indicate systematic differences (125). To quantitatively describe the intra-subject variability between sessions, the standard error of measurement (SEM) and the minimum detectable change (MDC) were calculated. SEM was calculated as the standard deviation (SD) of the mean differences between test and retest divided by $\sqrt{2}$. MDC is calculated as $1{,}96*\sqrt{2}*SEM$ (126) and defines the limits within a change in the measurement score that could be attributed to measurement error. MDC is also related to limits of agreement, as a true change in measure is only statistically significant and not due to measurement error, if the change in measure is outside the 95% LOA (127).

Coefficients of reproducibility and concurrent validity were assessed by the concordance correlation coefficient (CCC). The CCC assesses reliability as well as the ICC does (128, 129). In the analysis of concurrent validity, CCC was calculated on the first session of tests for both platforms. Interpretations of CCC or ICC point estimates are not yet agreed upon (86, 130-132). In the current study CCC point estimates ≥ *0.70* were interpreted as satisfactory.

Motor performance as predictor of injuries (Paper II)

Covariates to consider

Injuries

The influence of gender in relation to injury risk is not agreed upon. Two recent reviews concluded contradictory findings (64, 133). One reported boys generally tended to be at greater risk of traumatic injury than girls, but in specific sports types, soccer, basketball and baseball, girls have higher risk of injury than boys (64). The other reported girls to be at greater risk of traumatic injuries, especially knee injuries (133). The explanation of these contradictory finding could be, that studies on injuries are often sports specific or gender specific, and might include different exposure time or age groups. The different methodologies complicate the possibility of comparing studies.

Across sports types, the oldest children were found to be at greater risk than younger children: increasing age is consistently positively associated to increased injury risk (64). The increased risk in the older children could be explained by greater exposure to training or that older athletes often perform the most advanced and complex skills resulting in greater risk of failure. Pubertal stage has been reported to influence injury rates in adolescents, peri-pubertal sports participants had higher injury rates than pre – or post pubertal sports participants (134, 135). The decreased physeal strength and increased muscle-tendon tightness following the growth spurt during puberty is also reported as factors associated to increased injury risk (136) (137). This might influence the risk of traumatic injuries as the bone mineralisation may lag behind the increase in bone length thus leaving bone structures more susceptible for injuries. For overuse injuries the pathology is more prone to the tensile traction on the apophyses, as mentioned previously, leaving the child with pain over the apophyseal region. The elevated injury risk in more mature athletes could be explained by the possibility of the more mature athletes being more exposed to sports and consequently also more exposed to sustain an injury.

As heavier weight produces greater forces it has been hypothesized to influence risk of injuries. A recent study reported overweight in children to increase the risk of lower extremity injuries (138) and it has been indicated that overweight measured as body mass index (BMI) increased the risk of ankle sprains and the overall injury risk in football players and gymnasts (133, 138)

A previous injury may lead to an increased risk of sustaining future injury, possibly due to persistent symptoms and underlying physiologic deficiencies i.e. muscular weakness and imbalance, low endurance, impairment of ligaments, proprioception and fear of re-injury (139, 140). Having had a previous injury was identified as a risk factor in studies of adults with relative risks ranging from 2.88 to 9.41 (64). Previous ankle sprain has been shown to increase the risk of re-sprain (79-81), and as mentioned previously, traumatic injury e.g. sprains of the knee and ankle may lead to long-term consequences, e.g. complaints or swelling (51, 54). We only identified a few studies, which addressed the problem in a childhood population. In a Dutch school cohort study, 38% of injuries were considered re-injuries, but criteria for classifying injuries as re-injuries were not stated (141). When using the criteria of same body part, injury type, nature of onset and a history of injury the previous year a study in young (mean age: 12.6) female gymnasts showed a percentage of re-injuries of 32.7% (134). In a recent Danish study previous injury within the last eight weeks was shown not to influence present injury risk (142). Thus, despite emerging evidence, it still seems unclear, how important previous injury is with regards to the risk of sustaining a new injury in a child population. To our knowledge, the causality between a risk factor and risk of the first injury has not yet been established. Thus, as an example poor performance could lead to the first injury or the first injury could lead to poor performance.

Some schools offered six physical education lessons per week and others only offered two physical education lessons per week. When comparing injury rates in physical education lessons, leisure time and in organised sports participation, it is evident, that participating in organized sports results in the highest risk of injury (142), especially lower extremity injury risk (138). This is supportive of the common understanding that increased exposure time increases the risk of injuries.

The above reasoning suggests the need to adjust for sports participation, age, school type, BMI, pubertal stage and gender when investigating possible predictors of injuries in children, and possibly also to adjust for previous injury.

Statistical analyses

The primary exposure variables were the Andersen test, sway tests, shuttle run test, prone bridge test, side bridge test, vertical jump test and single leg hop for distance tests. The outcome variables were traumatic injuries of lower limbs, traumatic injuries in the knee region, traumatic injuries in the ankle region, overuse injuries of lower limbs, overuse injuries in the knee region and overuse injuries in the foot region

Since more participants reported zero injuries than one or more injuries, the data included an excessive amount of zeros. To model count variables with excessive zeros, we examined whether the zero-inflated negative binomial model, the zero-inflated Poisson regression, the Poisson regression or the negative binomial regression produced the best model fit of the data. These models allow the participants to be presented with more than one injury and the effect of explanatory variables and covariates were examined, along with modelling the risk of getting an injury and the number of injuries. All analyses were checked for model fit using difference between predicted and observed counts of injuries and the Vuong test statistics with the Bayesian Information Criterion correction (143). Depending on the result of the model tests, the method with the best fit was chosen.

Analyses were performed on standardized measures. As the model is a standard negative binomial model, coefficients are interpreted to IRR by IRR= exp (1SD* coefficient) (144, 145).

As an inclusion criteria it was decided that the parents of the participants had to answer at least 49 weeks (80%) of the possible 62 weekly SMS-track questions to be included in the analyzes. This led to exclusion of 13% of the participants.

Analyses were all adjusted for age, body mass index (BMI), pubertal stage, gender, school type (defined as control school or sports school according to the amount of physical education lessons as explained previously), and sports participation (defined as mean sports participation per week). Furthermore, the un-established relationship between previous injury and motor performance and / or injury risk resulted in performing the analyses with and without adjustment for previous injury. Previous injury was defined as previous traumatic ankle injury or traumatic knee injury in a period of 12 months before baseline.

Longitudinal associations between motor performance and physical activity (Paper III)

Covariates to consider

Physical activity

The correlates of PA are many and multifaceted (7). Although overweight and fatness logically should be inversly associated to the level of physical activity, previous reviews did not report body mass index (BMI) or skinfold measure to be significant associated to physical activity level in children (24, 25, 146). However, a recent study found overweight and fatness to be associated to low levels of physical activity in children (147). In particular, the study suggested adiposity to be a better predictor of PA than the other way round.

It is well known, that the level of physical activity is dependent on gender. Reviews of correlates of physical activity in children reported boys to be more physically active than girls, and found boys to spend more time at higher intensity levels than girls (24, 25).

As PA declines through adolescence (26, 27), age and / or puberty may affect the PA level. But as children of the same chronological age vary in biological maturity status, the impact of age may be different from the impact of pubertal stage (16).

A review on correlates of PA identified socioeconomic status to be associated with PA in children (24). In particular parental educational level was reported to be positively associated to physical activity level and negatively associated to the amount of sedentariness in children (24).

The above reasoning suggests gender, age, puberty stage, BMI, parental education and previous physical activity to be important correlates to influence PA, and, depending on their relation to motor performance, also possible confounders, to be taken into account when examining and analysing associations of present PA.

Statistical analyses

The primary outcome variable was mean percentage of time in moderate to vigorous physical activity (Mean MVPA per day) and the primary exposure variable was FMP at baseline.

The T-Test or Wilcoxon Rank-Sum Test was used to compare descriptive data between sexes. In order to examine FMP tests as predictors of Mean MVPA per day, multilevel mixed effects linear regression models were applied due to the hierarchal structure of the data with participants nested in school classes and school classes nested in schools. The mixed effects model takes into consideration the interdependence between measurements. The ICC was calculated to examine if a two-level model including both school class and school was better than a single level model including only school class. The ICC for including school class as a level was 0.075, and the ICC for including school level was 0.0003. Thus, school level did not improve the model fit, and therefore only school class was included as a random effect variable. Checking assumptions for the multilevel mixed effects linear regression models included checking of the distribution of the residuals.

Analyses were performed on single FMP tests and on composite Z-scores. For each of the FMP variables, a Z-score was computed as the number of standard deviation (SD) units from the sample mean after normalization of the variables, i.e., Z = (value − mean/SD). The Z-scores were multiplied by −1 if better performance was expressed as lower values, to introduce a higher degree of FMP with increasing value. Finally, the Z-scores were summed to the composite Z-score categories 'health-related fitness' or 'performance-related fitness' and divided by the number of included variables.

Stepwise model building was performed, and Akaike´s information criterion was run on the final random intercept model and on a corresponding random slope model. The model with the lowest value of Akaike's information criterion was interpreted as the model with the best fit. Interaction between sex and FMP was tested. There were significant interactions between sex and the agility run test, the Andersen test, and the Z-score of health-related fitness, thus in those analyses we included an interaction term.

Some children had four weekdays of PA data registered but no weekend days, which excluded them from the weighted analyses. We compared analyses including these children with missing data on weekend days with the estimates of children with weighted PA data and found no influential difference in parameter estimates or significance levels. Thus, we chose to include participants with missing weekend days, if they had at least four weekdays of PA data registered, in order to gain more power.

All analyses were controlled for baseline values of the following possible confounders: Mean MVPA per day, sex, age, body mass index (BMI), parental educational level, puberty (24, 146, 148, 149) and type of school, since the number of physical education lessons per week differed between schools in the CHAMPS Study-DK (42).

Results

In this section the basic descriptive statistics covering the anthropometrics of the participants in each paper are presented in Table 2. For descriptive information on the sway data, FMP data, injury data and the PA data from the participants of each study, the reader is referred to the results section of each manuscript.

Table 2

Baseline characteristics of study participants included in paper I, II & III

Paper	**N**	**Gender (% male)**	**Age (yrs(range))**	**Height (cm(SD))**	**Weight (kg(SD))**	**BMI (kg/m^2)**
I	54	45	11.5 (10-14)	154.7 (9.9)	44.1 (10.3)	18.6 (2.9)
II	1084	48	11.2 (8-14)	151.8 (10.9)	42.2 (10.5)	18.1 (2.7)
III	673	44	9.2 (6-12)	136.9 (9.5)	31.9 (7.3)	16.8 (2.2)

Reproducibility and concurrent validity study (Paper I)

The first study examined the reproducibility of the NWB and the AMTI force platform, and the concurrent validity of the NWB when compared to the AMTI force platform. Of the 58 possible participants 54 participants were included in the study. Four participants were excluded due to ankle injury and difficulties in satisfactory completion of the tasks.

Test-retest reproducibility of NWB and AMTI

In the study of the reproducibility of the NWB, Bland-Altman plots of the average COPL (Figure 2) demonstrated no systematic bias. The range of LOA varied from -17.0 to 17.0 cm in the bilateral eyes-open test and -38.9 to 34.9 cm in the test for the dominant leg.

For the NWB, the CCC was ≥ 0.70, ranging from 0.76 to 0.83. The MDC varied between 16.9 cm and 36.9 cm (26.5-28.6% of the mean COPL). The mean COPL difference was highest for the unilateral test on the non-dominant leg.

For the AMTI, Bland-Altman plots (Figure 3) demonstrated no systematic bias in three of the four tests. In the unilateral test on the non-dominant leg, however, the differences increased with larger values, and the observed agreement indicated shorter COPL on retests. The range of LOA varied between -12.8 to 16.9 cm in the bilateral eyes-open test and -29.2 to 43.0 cm in the test for the dominant leg.

For the AMTI, CCC values for COPL were ≥ 0.70 in all four tests, ranging from 0.79 to 0.86. MDC varied between 14.7 and 36.1 cm (26.3 - 28.1% of the mean COPL). The highest mean differences were seen in the unilateral tests.

As all the trials lasted 30 seconds, the LOA, MDC and mean differences are results per 30 seconds sway test.

Figure 2. Bland-Altman plots of reproducibility of the Nintendo Wii Board.

EO= Eyes Open, EC= Eyes Closed, 95% loa= 95% limits of agreement, COPL: Centre Of Pressure path Length, COPL1=COPL test, COPL2= COPL re-test

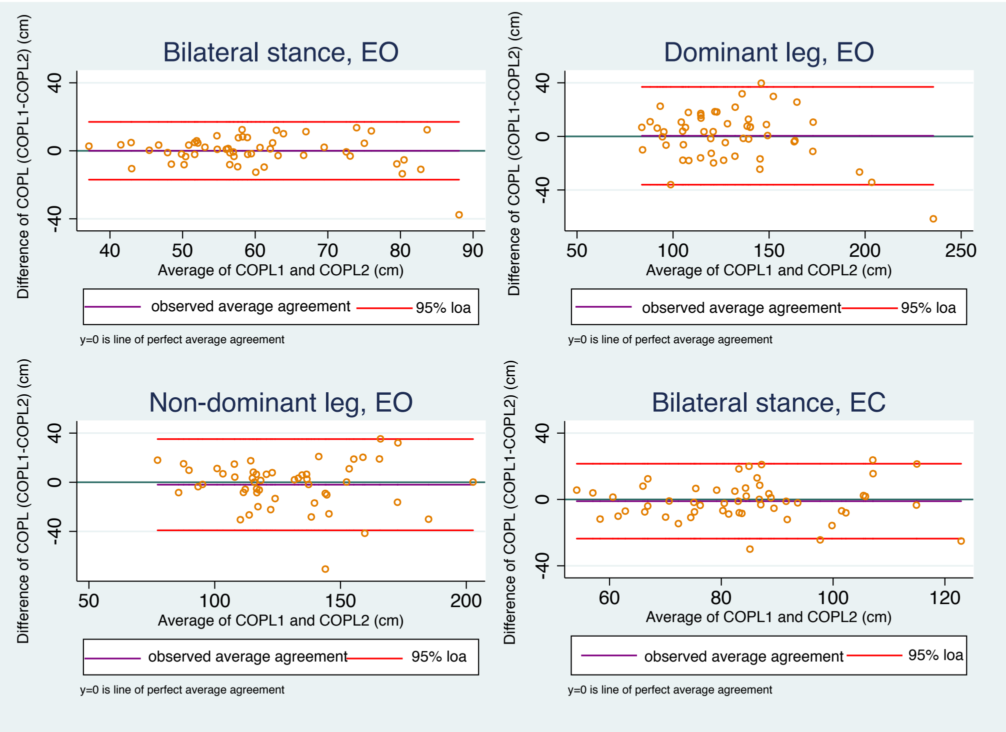
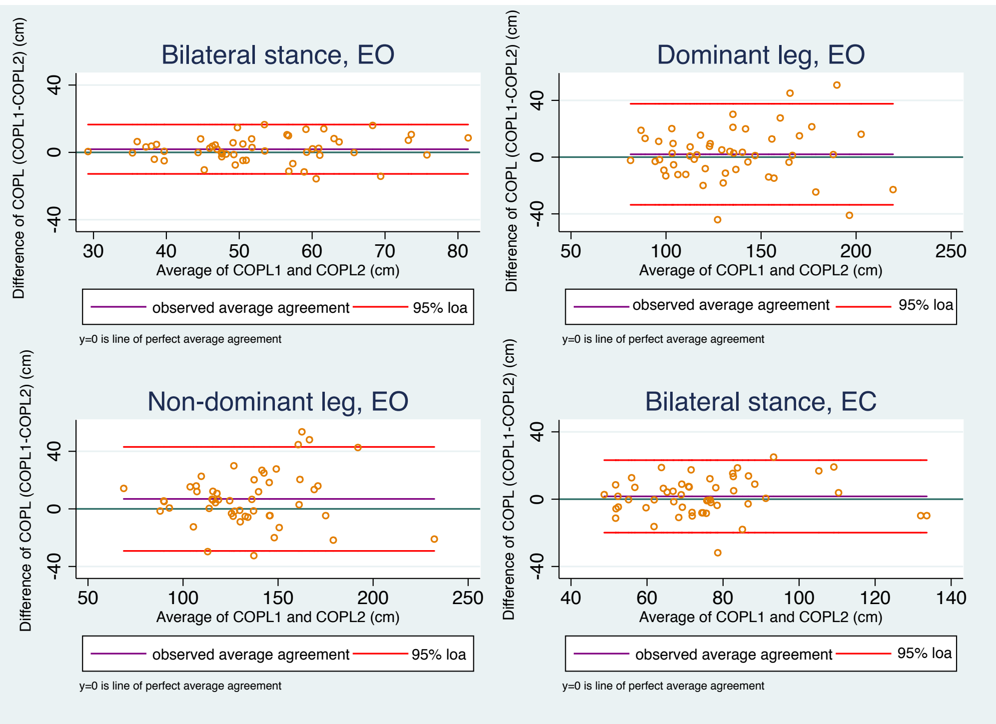


Figure 3. Bland-Altman plots of reproducibility of the AMTI force platform.

EO= Eyes Open, EC= Eyes Closed, 95% loa= 95% limits of agreement, COPL: Centre Of Pressure path Length,

COPL1=COPL test, COPL2= COPL re-test



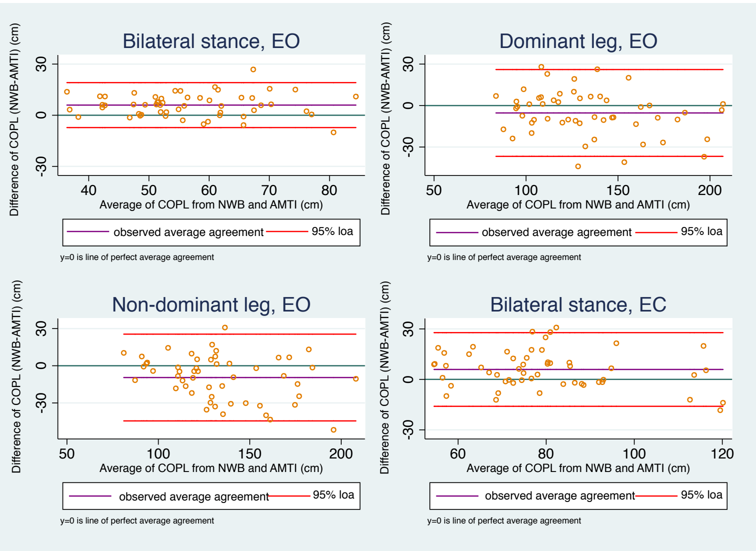
Concurrent validity

In the study of the concurrent validity of the NWB compared to the AMTI force platform, Bland-Altman plots (Figure 4) demonstrated no systematic bias, except for the unilateral test on the non-dominant leg that showed a slight funnel effect, with larger differences between the two measurement devices as the sway measures increased.

LOA showed larger variation in the unilateral tests than in the bilateral tests and the line of observed agreement indicated that the NWB gave longer measurements in bilateral tests (mean difference varied from 5.96 to 5.99 cm), but shorter measurements in unilateral tests (mean difference varied from 5.33 to 9.5 cm) (Figure 4). The range of LOA varied between -7.2 cm to 19.1 cm in the bilateral eyes-open test and -44.5 cm to 25.5 cm in the test for the non-dominant leg.

Figure 4 Bland-Altman plots of concurrent validity, Nintendo Wii Board and AMTI force platform.

EO= Eyes Open, EC= Eyes Closed, 95% loa= 95% limits of agreement, COPL: Centre Of Pressure path Length, COPL1=COPL test, COPL2= COPL re-test



Point estimates of concurrent validity were satisfactory (CCC=0.74-0.87). The mean difference was highest for the unilateral test on the non-dominant leg.

Summary

In the reproducibility study, only one of the eight Bland-Altman plots revealed a systematic bias (AMTI, unilateral test on the non-dominant leg). The CCC coefficients were ranging from 0.76 to 0.83 and slightly higher in AMTI, whereas MDC and LOA were comparable for the NWB and AMTI.

In the validity study both the 95% LOA and the CCC coefficients are comparable to the results from the test-retest study. The CCC coefficients were in the range of 0.74 to 0.87.

Motor performance as predictor of injuries (Paper II)

In the study of motor performance as predictor of injuries in children, 162 participants of the 1246 possible participants were excluded due to missing SMS-Track data. The exclusion left 1084 participants with complete data.

A total of 874 injuries in the lower extremity were registered in the follow up period, including 651 overuse injuries and 223 traumatic injuries. Traumatic injuries of the foot region were more common than in the knee region (Figure 5), whereas overuse injuries were more common in the knee region than in the foot region (Figure 6).

Figure 5 Traumatic injuries, shown by region and type

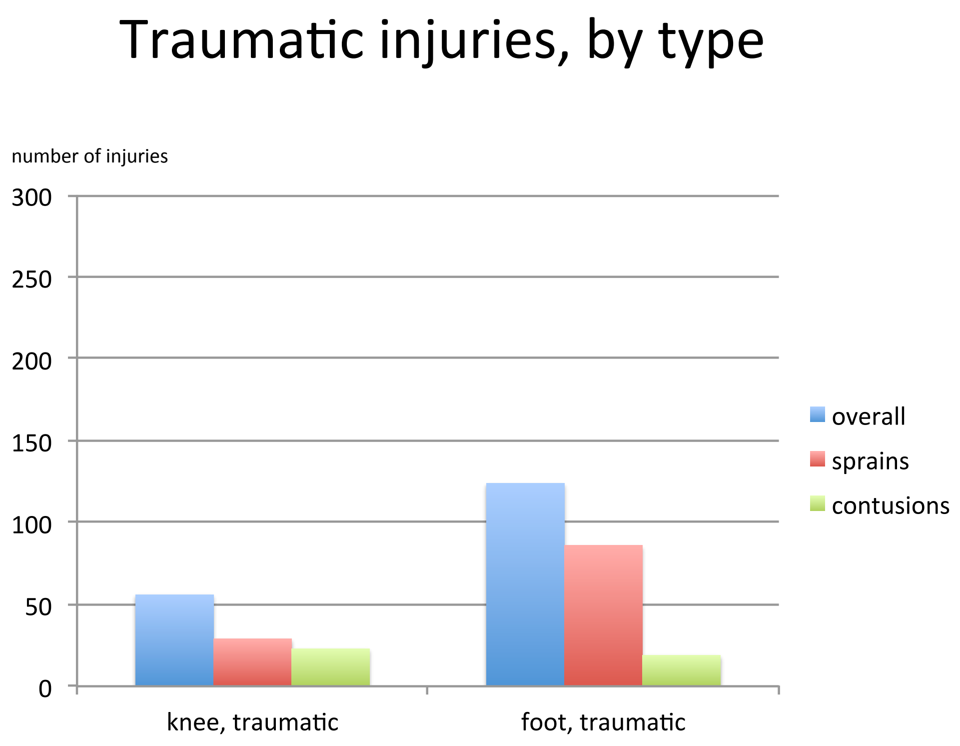
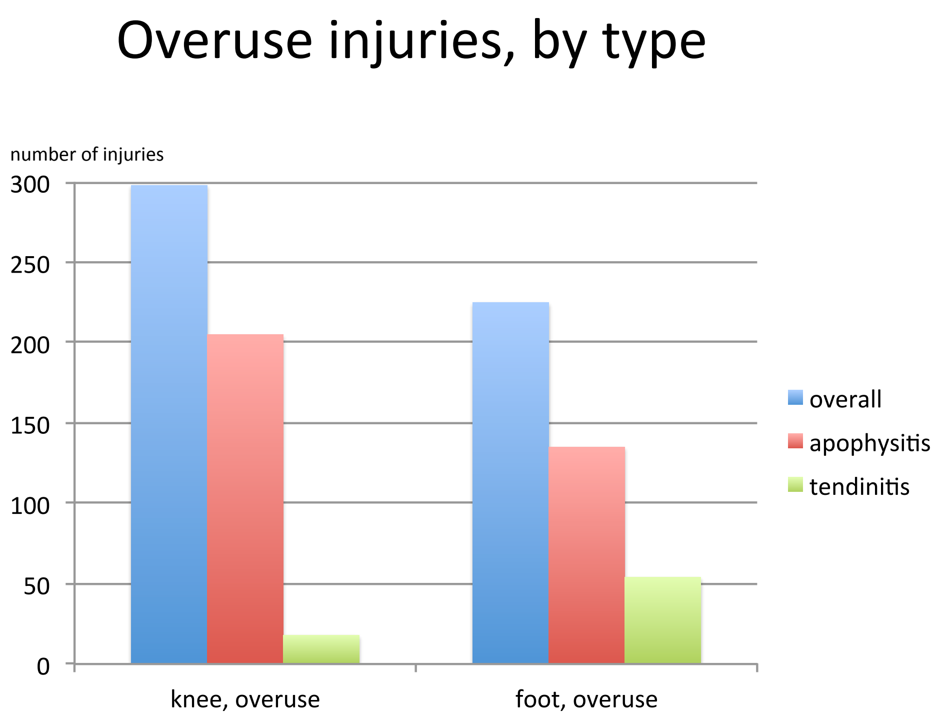


Figure 6 Overuse injuries, shown by region and type



The results of the regression analyses of the single FMP tests as predictor of traumatic and / or overuse injuries in children are presented in Table 3a and Table 3b. The tables present the IRR when changing the performance measure 1 SD.

Traumatic injuries

As described in the methods section, we chose to run the analyses with and without adjustment for previous injury. The analyses not adjusted for previous injury showed significant results in three of four sway measures for total traumatic injuries (IRR 1.10-1.13), and similarly, for traumatic injuries in the foot region (IRR 1.14-1.15), reflecting poor sway performance (longer COPL) to increase injury risk (Table 3a). When adjusting for previous injury, two of the four different sway measures still remained as significant risk factors of traumatic injuries, again showing longer COPL to increase the risk of total traumatic and ankle/foot injuries (sway in bilateral stance, open eyes IRR=1.06, unilateral stance on non-dominant leg IRR=1.09) (Table 3a). The two remaining sway tests for total traumatic injuries, ankle injuries and all sway tests for traumatic knee injuries were pointing in the same direction, but only borderline significant/non-significant (Table 3a).

Good performance in single leg hop for distance (dominant leg) was protective of traumatic injuries of the knee both in the unadjusted (IRR=0.66) and adjusted model (IRR=0.68), indicating longer jump to decrease knee injury risk.

Good performance in prone bridge, side bridge and vertical jump increased the risk of traumatic injuries of the foot significantly in the unadjusted model (IRR 1.12-1.16), while only borderline significantly related to risk in the adjusted model for prone and side bridge, indicating better performance to increase total/ankle injury risk. Vertical jump height did not remain significant in the adjusted model. Previous injury was significantly related to all outcomes.

Table 3a. Risk of traumatic injuries. Results of regression analysis of standardized measures showing Incidence Rate Ratios (IRR) with 1 Standard Deviation change in performance.

	Total traumatic injuries, lower extremity		Knee injuries		Ankle / foot injuries	
	Standardized IRR^{a} unadjusted (95% CI)	*Standardised IRR, adjusted (95% CI)*	*Standardized IRR^{a} unadjusted (95% CI)*	*Standardised IRR, adjusted (95% CI)*	*Standardized IRR^{a} unadjusted (95% CI)*	*Standardised IRR, adjusted (95% CI)*
Sway bilateral stance, EO	1.10 ^{*b}	1.06 ^{*bde}	1.05 ^{b}	1.06 ^{be}	1.14 ^{*bd}	1.09 ^{*bde}
	(1.04 to 1.17)	(1.001 to 1.13)	(0.88 to 1.27)	(0.89 to 1.26)	(1.06 to 1.23)	(1.01 to 1.17)
Sway, dominant leg, EO	1.05 ^{bd}	1.04 ^{bde}	1.08 ^{b}	1.08 ^{e}	1.06 ^{bd}	1.04 ^{bde}
	(0.92 to 1.20)	(0.94 to 1.15)	(0.92 to 1.27)	(0.93 to 1.27)	(0.89 to 1.27)	(0.91 to 1.20)
Sway non-dominant leg, EO	1.13 ^{*bd}	1.09 ^{*bde}	1.14 $^{\#}$	1.14 $^{\#e}$	1.15 ^{*bd}	1.09 ^{*bde}
	(1.05 to 1.23)	(1.02 to 1.17)	(0.98 to 1.31)	(0.99 to 1.32)	(1.04 to 1.27)	(1.01 to 1.17)
Sway, bilateral stance, EC	1.10 ^{*bd}	1.06 $^{\#bde}$	1.07	1.08 ^{be}	1.14 ^{*bd}	1.08 $^{\#bde}$
	(1.01 to 1.20)	(0.99 to 1.14)	(0.91 to 1.27)	(0.91 to 1.28)	(1.03 to 1.26)	(0.99 to 1.18)
Agility run	1.03 ^{bde}	1.04 ^{bde}	0.98	0.99 ^{e}	0.97 ^{cd}	0.98 ^{bde}
	(0.87 to 1.22)	(0.89 to 1.22)	(0.73 to 1.31)	(0.74 to 1.31)	(0.81 to 1.16)	(0.82 to 1.16)
Prone bridge	1.15 ^{*bd}	1.11 $^{\#bde}$	1.07	1.06 ^{e}	1.16 ^{*bd}	1.09 ^{bde}
	(1.04 to 1.27)	(0.98 to 1.25)	(0.90 to 1.27)	(0.89 to 1.27)	(1.03 to 1.29)	(0.97 to 1.22)
Side bridge	1.08 ^{bd}	1.04 ^{bde}	0.84	0.83 ^{e}	1.14 ^{*bd}	1.08 $^{\#bde}$
	(0.96 to 1.21)	(0.94 to 1.15)	(0.59 to 1.20)	(0.59 to 1.18)	(1.02 to 1.28)	(0.98 to 1.17)
Single leg hop, dominant leg	0.95 ^{b}	0.96 ^{be}	0.66 ^{*b}	0.68 ^{*be}	1.06 ^{bd}	1.08 ^{bde}
	(0.78 to 1.16)	(0.79 to 1.17)	(0.51 to 0.84)	(0.53 to 0.87)	(0.84 to 1.34)	(0.85 to 1.37)
Single leg hop, non-dominant leg	1.06 ^{bd}	1.05 ^{bde}	0.85	0.87 ^{e}	1.07 ^{bd}	1.05 ^{bde}
	(0.88 to 1.27)	(0.87 to 1.26)	(0.59 to 1.21)	(0.60 to 1.25)	(0.88 to 1.30)	(0.87 to 1.26)
Andersen	1.06 ^{b}	1.05 ^{be}	0.95	0.92 ^{e}	1.10 ^{b}	1.08 ^{be}
	(0.84 to 1.34)	(0.83 to 1.33)	(0.60 to 1.50)	(0.61 to 1.39)	(0.84 to 1.46)	(0.82 to 1.43)
Vertical jump	1.08 $^{\#bd}$	1.05 ^{bde}	1.03	1.04 ^{e}	1.12 ^{*bd}	1.08 ^{bde}
	(0.99 to 1.18)	(0.97 to 1.13)	(0.85 to 1.25)	(0.86 to 1.26)	(1.01 to 1.25)	(0.98 to 1.18)

Analyses are adjusted for sports participation, age, sex, body mass index (BMI) and school type. Unadjusted analyses are not adjusted for previous injury, adjusted analyses are adjusted for previous injury.
CI=Confidence Interval, EO= Eyes Open, EC= Eyes Closed
a = IRR calculated as exp(1*coefficient)
b = sports participation significant, c= age significant d=BMI significant e=previous injury significant
* = $p \leq 0.05$
\# = $0.05 \leq p \leq 0.1$

Overuse injuries

Number of total overuse injuries showed significant associations to shuttle run (IRR=1.18), prone bridge test (IRR=1.09), and borderline significance to the side bridge test (IRR=1.07) (Table 3b). Prone bridge (IRR=1.16) and side bridge (IRR=1.12) were significantly associated with overuse knee injuries, shuttle run was borderline significantly related to injury risk of the knee, indicating better performance to increase injury risk. One of the sway tests, bilateral stance with closed eyes, showed poor performance (longer COPL) to significantly increase the risk of ankle overuse injuries (IRR=1.65).

Several covariates, in particular sports participation, age and gender (male) were significantly and positively associated to sustaining injuries in the foot region (Table 3b).

Table 3b Risk of overuse injuries. Results of regression analysis of standardized measures showing Incidence Rate Ratios (IRR) with 1 Standard Deviation change in performance.

	Total overuse injuries, lower extremity	Knee, overuse injuries	Ankle /foot, overuse injuries
	IRR, standardised (95% CI)	*IRR, standardised (95% CI)*	*IRR, standardised (95% CI)*
Sway bilateral stance EO	0.98 [b] (0.90 to 1.08)	0.95 [b] (0.84 to1.07)	0.90 [bec] (0.76 to 1.06)
Sway, dominant Leg, EO	0.98 [b] (0.89 to 1.08)	0.96 [b] (0.86 to 1.08)	0.93 [bec] (0.78 to 1.10)
Sway non-dominant leg, EO	1.01 [b] (0.93 to 1.10)	1.01 [b] (0.89 to 1.14)	0.94 [bec] (0.75 to 1.18)
Sway, bilateral stance, EC	1.02 [b] (0.95 to 1.10)	0.99 [b] (0.91 to 1.09)	1.65 [*bd] (1.24 to 2.19)
Shuttle run	1.18 [*bc] (1.07 to 1.31)	1.15 [#] (0.98 to 1.34)	1.10 [bc] (0.92 to 1.32)
Prone bridge	1.09 [*b] (1.01 to 1.17)	1.16 [*] (1.07 to 1.26)	0.99 [bec] (0.90 to 1.10)
Side bridge	1.07 [#b] (1.00 to 1.15)	1.12 [*bc] (1.03 to 1.24)	1.05 [bec] (0.93 to 1.18)
Single leg hop for distance, dominant leg	0.99 [b] (0.87 to 1.11)	0.89 [b] (0.76 to 1.05)	1.06 [bec] (0.90 to 1.24)
Single leg hop for distance, non-dominant leg	1.00 [b] (0.89 to 1.13)	0.94 (0.80 to 1.11)	0.97 [bec] (0.82 to 1.14)
Andersen	1.08 [b] (0.90 to 1.30)	1.07 (0.84 to 1.38)	0.98 [bec] (0.78 to 1.22)
Vertical jump	0.95 [b] (0.86 to 1.05)	0.90 [b] (0.76 to 1.07)	0.86 [bec#] (0.72 to 1.03)

Analyses are adjusted for sports participation, age, sex, body mass index (BMI) and school type.
CI=Confidence Interval, EO= Eyes Open, EC= Eyes Closed
a=IRR calculated as exp(1*coeffificient)
b=sportsparticipation significant, , c=age significant d=tanner significant e= gender significant
*=p≤0.05
#=0.05≤p≤0.1

Longitudinal associations between motor performance and physical activity (Paper III)

In the study of motor performance as predictor of PA, 1146 participants had baseline data on both FMP and anthropometrics. Exclusion due to in-complete data resulted in 673 participants in the analyses on FMP as predictor of PA (Figure 7).

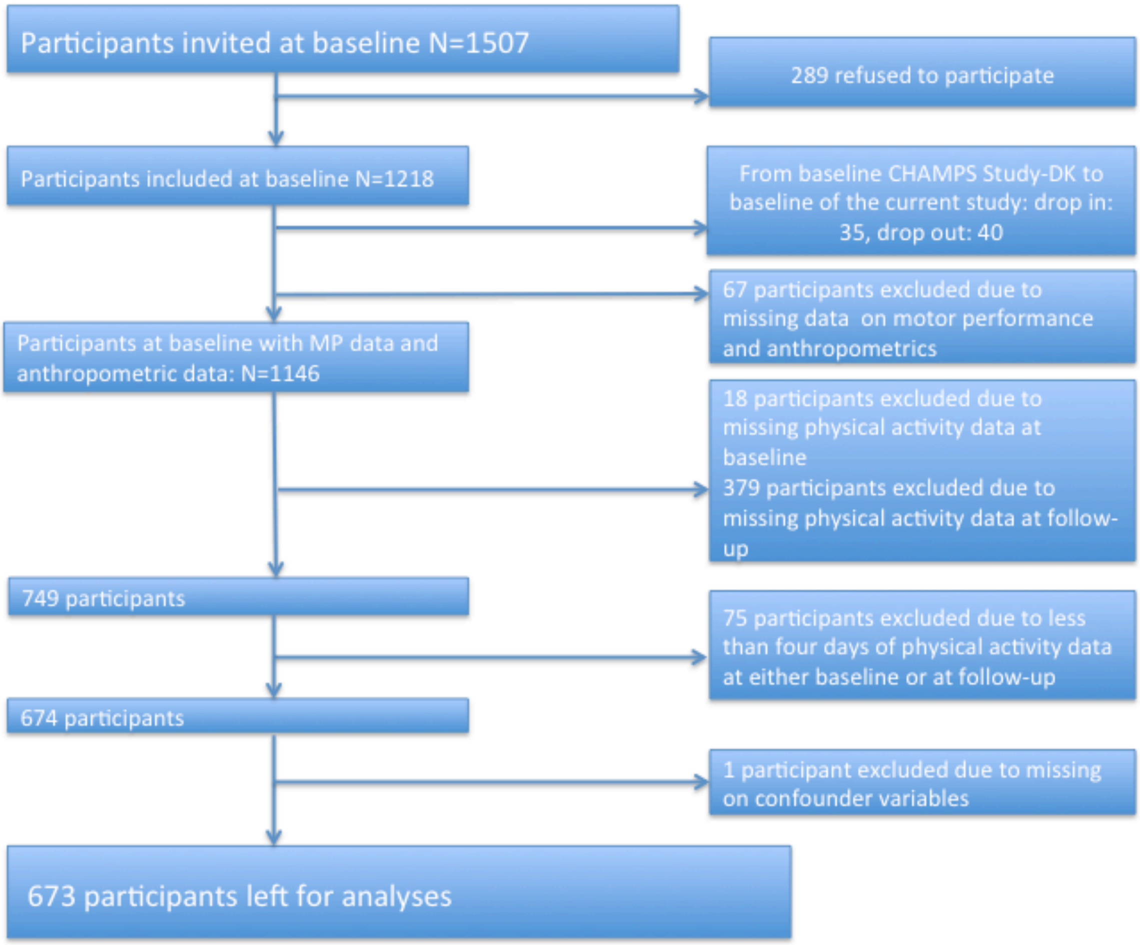


Figure 7 Flow-chart of the participants

The multilevel mixed effect linear regression showed significant positive associations between baseline FMP measures and three-year follow up measures on PA. Significant positive associations were seen between baseline performance of the Andersen test and mean MVPA per day at follow-up (for boys: β=0.008, for girls: β=0.003), baseline performance of vertical jump and mean MVPA per day at follow-up (β=0.04), baseline performance of handgrip and mean MVPA per day at follow-up (β=0.06), baseline Z-score of health-related fitness and mean MVPA per day for boys at follow-up (β=1.09), and baseline Z-score of performance-related fitness and mean MVPA per day at follow-up (β=0.58) (Table 4). A significant inverse association was evident between shuttle run and mean MVPA per day for boys (β=-0.26), and for girls (β=-0.13) (Table 4).

Table 4. Associations between fitness-related motor performance tests from 2009 and mean percentage of time spent in moderate to vigorous physical activity in 2012.

	n	Coefficient (95% CI)	Standardized coefficient (95% CI)	p-value
Balance (point)	672	0.01 (-0.006 to 0.026)	0.13 (-0.07 to 0.33)	0.206
Precision throw (point)	673	0.04 (-0.006 to 0.09)	0.20 (-0.03 to 0.43)	0.088
Handgrip (kg)	673	0.06 (0.002 to 0.113)	0.27 (0.01 to 0.53)	0.042
Shuttle run[a] (seconds)	667			
Boys		-0.26 (-0.42 to -0.11)	0.70 (0.30 to 1.11)	0.001
Girls		-0.13 (-0.22 to -0.04)	0.35 (0.11 to 0.59)	0.004
Vertical jump (cm)	673	0.04 (0.002 to 0.07)	0.23 (0.013 to 0.44)	0.038
Andersen test[a] (m)	642			
Boys		0.008 (0.005 to 0.012)	0.87 (0.48 to 1.26)	0.000
Girls		0.003 (0.0001 to 0.005)	0.27 (0.01 to 0.54)	0.042
Health-related MP[a] (Z-score)	642			
Boys		1.09 (0.52 to 1.66)		0.000
Girls		0.34 (-0.03 to 0.71)		0.068
Performance-related MP (Z-score)	667	0.58 (0.24 to 0.93)		0.001

n=number of participants, 95% CI= 95% confidence Interval, Health-related MP (Z-score) = Z-score of the items Andersen test and handgrip, Performance-related MP (Z-score)= Z-score of the items balance, shuttle run, vertical jump and precision throw.

All analyses were adjusted for sex, baseline physical activity, puberty stage, age, body mass index, school type and parental educational level

p-value: level of significance was 0.05.

[a]=significant interaction by sex

Post estimations were performed on selected FMP measures, using predictive margins to estimate differences in outcome when the exposure variable changed by 1 SD from the mean value (standardized results are presented in Table 4). The largest impact on mean MVPA per day was found in changes in the Andersen test (Table 4). Thus, decreasing the Andersen test by 1 SD for a boy changed the mean MVPA per day with 0.87 percentage points equivalent to a decrease in mean MVPA per day from 61.7 minutes to 54.0 minutes.

Non-compliance analysis showed that participants not included in the analysis due to missing data on either baseline PA or follow-up PA did not differ significantly from the included participants in results regarding FMP, except for handgrip, where the excluded participants performed better. The participants not included in the analyses differed significantly from the included participants on baseline anthropometrics, as included participants were characterized by lower height, lower weight, lower BMI, and they were younger and had a lower pubertal stage.

Discussion

Overall the results of the current thesis indicated:

1. The NWB is a reproducible and valid tool for measuring sway of children in a field setting, and that NWB and AMTI possess equal reproducibility of COPL in children
2. Increased sway and a test of functional capacity of the knee were significant predictors of traumatic injuries. Shuttle run, side bridge and prone bridge performance indicating good performance increased the risk of overuse injuries in total and overuse injuries in the knee region, while poor performance in bilateral sway with eyes closed was indicated to be a risk factor of overuse injuries in the knee region.
3. A clear positive and significant association was evident between baseline FMP and mean MVPA per day at three-year follow-up for the Andersen test, vertical jump, shuttle run, handgrip, the Z-score of health-related fitness and the Z-score of performance-related fitness in both boys and girls.

Based on the two longitudinal studies of this thesis it was possible to investigate motor performance tests as predictors of the health outcomes physical activity related injuries and PA respectively. Thus, this thesis can contribute to the knowledge on the importance of childhood motor performance in a health perspective.

The following discussion will take the previously mentioned specific objectives of this thesis as a starting point, including methodological considerations and followed by a discussion of the main strengths and limitations of this thesis in general.

Reproducibility and concurrent validity study (Paper I)

The main findings of paper 1 were that NWB is a reproducible and valid tool for measuring sway of children in a field setting, and that NWB and AMTI possess equal reproducibility of COPL in children (based on 95% LOA, MDC and CCC>0,70). Furthermore, a possible measurement error in the validity of the NWB towards AMTI is small compared to the intra-subject variability, since 95% LOA and CCC of NWB when compared to the AMTI, is comparable to 95% LOA and CCC of the test-retest study. As this was the first study to examine reproducibility and concurrent validity of the NWB in a population of children, comparisons of CCC estimates, MDC values and conclusions are made to studies of sway measures in adult populations. Comparisons of MDC values to previous studies are limited, as only few studies on COPL as a balance measure, reported MDC (101). Comparing our findings with studies of adult populations, our findings are in line with previous studies reporting reproducibility and concurrent validity to be satisfying (85, 102, 150, 151).

Bland-Altman plots illustrating the reproducibility of the NWB and AMTI showed similar results, confirmed by CCC > 0.70 (CCC 0.76-0.86). The MDC of NWB in percentage was relatively high (26-28%) in the current study, but in line with a previous study (85), and was similar to that of the AMTI. The relatively large LOA and MDC indicated large variation between trials, which questions the validity of the CCC. The importance of the variation in MDC and LOA, and the influence on determining the appropriateness of using NWB and AMTI to measure sway is unknown, but needs examination in future studies as it might influence the usefulness of NWB and AMTI measures as predictor of injuries or risk of falls. However, the AMTI was shown to be sensitive enough to predict injuries from sway measures (76), and the NWB was found sensitive enough to detect postural changes associated with subtle variations in visual tasks in elderly people (152).

Methodological considerations

Time of day

In previous test-retest studies on sway variables, the time interval between test and retest varied from a few minutes to several days and seemed to be arbitrarily chosen (83-85, 111, 153). Previous studies have concluded that time of day may influence sway measures (154, 155). In the current timespan of two hours, Bland-Altman plots and reliability coefficients showed satisfactory test-retest, but more studies are needed to examine time-of-day and day-to-day variation in sway measures among children and adolescents.

Measurement error
The measurement error of the NWB is difficult to assess directly, but by comparing LOA from the validity study with LOA in the reproducibility study, it is possible to have an indication of the size of measurement error of the NWB. As the LOA and CCC coefficients in the reproducibility study are comparable to the LOA and the coefficients in the validity study, the measurement error due to the NWB is probably small compared to the intra-subject variability. CCC for COPL was satisfactory (CCC 0.74-0.86).

Interpretation of CCC values
The cut-off point for interpreting CCC values was chosen because of similarities in interpretation between CCC and ICC (128, 129), and to make this field study in a child population comparable with the two other studies that evaluated both concurrent validity and reproducibility of the NWB (85, 150). Although cut-off points for interpreting the ICC value are not yet agreed upon (86, 130-132), the agreement of all four tests is convincing when the variable of interest is COPL.

Children versus adults
The CCC of all tests in the present study was generally lower than in previous studies in adult populations (85, 102, 150, 151). The reason for these differences is not known but may be due to lack of full motor control development of the participants, resulting in less secure balance (89-92) and large intra-subject variability because of more variation between test and retest. Perhaps the ability to focus on the task was different from studies of adult populations. These issues are important in determining which age groups the sway measurements are relevant for, and especially whether they are relevant for children who are younger than the participants in the current study.
We found higher SEM, mean differences and larger LOA in the unilateral tests than in the bilateral tests, both in the test-retest analysis and in the validity analysis. This difference is mainly ascribed to an anticipated higher level of difficulty due to the smaller medial-lateral base of support area in single-leg tests compared to bilateral tests. The performance of the participants will be more homogeneous in the bilateral tests, since variation between the trials is smaller. However, in some populations, maybe age dependent, there may be floor effects when using only bilateral balance tests.

The median as the outcome variable
The choice to use the median as a primary outcome variable was based on a similar study by Clark et al. (85). To our knowledge it is still unknown if the best and most representable variable of sway and the reproducibility of tests is achieved by choosing the median value, the mean value, the best performance of sway (the shortest COPL) or the poorest sway performance (the longest COPL). In a pilot-study (156) we investigated the reproducibility on seven parameters: all three trials (1st, 2nd, and 3rd trial), Minimum COPL of the three trials, Median of the three trials, Mean of the three

trials, and maximum COPL of the three trials. The conclusion was, that the minimum COPL, the Median value of COPL, and the mean value of COPL demonstrated the best and most similar values of reproducibility.

Overall, the reproducibility of the NWB and the AMTI was satisfactory as were the concurrent validity of the NWB when compared to the AMTI. Thus, if the variable of interest is COPL, the results for the NWB are comparable to those for the AMTI, confirming previous studies (85, 150). In favour of NWB is further, that it is economically feasible to measure sway in large populations, due to the small size, light weight, and that it is easy to use and cheap compared to advanced instruments. The impact of the intra-subject variability on the precision and feasibility of the equipment when used in clinical settings, field studies and studies of injury prediction are yet to be examined, as is the reproducibility of NWB and AMTI in children younger than the current study population.

Motor performance as predictor of injuries (Paper II)

The main findings of this study were that increased sway and a test of functional capacity of the knee were significant predictors of traumatic injuries (Table 3a). In particular, sway measures seemed to be consistent predictors of traumatic injuries in the ankle region, as several significant results, supported by borderline significant results, showed that injury risk increased with increased sway. For each SD increase in sway the IRR increased with 10-15% in the analyses not adjusted for previous injury, and by 6-9% in the analyses adjusted for previous injury.

For overuse injuries the results of the analyses of shuttle run, side bridge and prone bridge performance indicated, that good performance increased the risk of overuse injuries in total and overuse injuries in the knee region. At the same time, poor performance in bilateral sway with eyes closed was also indicated to be a risk factor of overuse injuries in the knee region.

This study is the first large-scale study to include sway performance to examine if sway performance in children can predict injury. Furthermore, the separate analyses of motor performance tests as risk factors for overuse injuries, is new.

Traumatic injuries

Low skill level a risk factor of injury

In both adjusted and un-adjusted analyses the results showed that bilateral sway tests and unilateral sway tests were significant predictors of traumatic injury, longer sway measures increasing the risk of traumatic injury. This result is supportive of previous studies on the relation between balance and injuries in adult populations (69, 76, 77) examining risk factors of traumatic injuries of the ankle joint, primarily sprains. Thus, the results of the current study supports the hypothesis that an adequate postural control is important in relation to injury prevention in youth, in particular in the ankle region. The results of sway analyses related to the knee region were borderline significant or non-significant, but pointing in the same direction as for the other groups of analyses. This could be related to the relatively few traumatic injuries in the knee region compared to the more frequent traumatic injury in the ankle region, thus, it could suggest a type 2 error (Figure 5 (and Table 2 in Paper II)). The reason for the non-significant results related to sway performance on the dominant leg is unknown. As measures of sway in children has been shown to be affected by large intra subject variability and large minimal detectable change of especially the one-legged tests (157), this could be a possible explanation and perhaps affecting the estimates and the significance.

To reflect the clinical impact of changing the predictors we chose to present the results as IRR when exposure variables changed by 1SD. In example, if IRR =1.09 (Table 3a) the risk of traumatic injury of the ankle increases by 9% if COPL increases by 1SD. For traumatic injuries in the ankle region a change in the measures of bilateral sway with closed eyes by 1SD equivalents 1.3 cm excessive sway per second.

For traumatic knee injuries the single leg hop for distance test was inversely associated to injury risk in adjusted and un-adjusted analyses, suggesting good performance to be protective of injuries. The single leg hop for distance is a valid and reliable measure of functional capacity of the lower extremity (105), as it measures a combination of power, strength, proprioception, balance and coordination(158). Only one of the two single leg hop for distance tests was significant. However, both tests pointed in the same direction. Thus, this finding could be a chance finding or it could indicate, that good functional capacity of the lower extremity is important to avoid a traumatic injury of the knee joint. Thus, this finding could indicate, that these abilities are important to avoid a traumatic knee injury, which is in line with previous studies on adults (159).

Cardiorespiratory fitness (the Andersen test) was not associated to the risk of traumatic injury. This result is different from previous studies in adults showed low cardiorespiratory fitness to be associated to higher risk of injuries (63, 64, 69, 73). A possible explanation of these differences could be the current study examining a population of children. Children might behave differently from adults when getting exhausted, allowing themselves to have a break instead of continued competition.

High skill level as a risk factor for injury

In the un-adjusted analyses several performance tests showed significant results (Table 3a). When adjusting the analyses for previous injury the results regarding the vertical jump, the prone and side bridge tests became non-significant. The two borderline significant results in the adjusted analyses still indicated good performance to be a risk factor for traumatic injury. As only two analyses pointed in the direction of high skill level to be a risk factor for traumatic injury this could be a chance finding.

But as both adjusted and un-adjusted results were in line with previous studies showing high skill-level in general, to be positively associated with the risk of ankle sprains in adults (soccer players) (69) or injuries in general in youth females (soccer) (70) the results cannot be dismissed. The explanation may be that high skill-levels could be a risk factor due to the higher volume and intensity of play with potentially also higher exposure to tackles and foul play. However, the exact reason cannot be ruled out from the current study. The different relation between different tests and risk of injury, some analyses pointing toward high skill level to be a risk factor others pointing towards low skill level to be a risk factor, perhaps could be explained by single leg hop for distance and sway expressing some components of motor control, and the vertical jump, prone bridge and side bridge tests expressing other components. This is for future research to clarify.

Overuse injuries

Low skill level as risk factor of overuse injury

The association between low skill-level i.e. poor balance (longer COPL in bilateral stance with eyes closed) and overuse ankle injuries, pointed in the same direction as for traumatic injuries. However, this result may be a chance finding since results of the remaining sway tests were generally pointing oppositely. If poor sway performance is also a risk factor of overuse injury, the injury mechanism is not similar to that of traumatic injuries. The reasoning is different though, as the injury mechanism of overuse injuries is not similar to the injury mechanism of traumatic injuries. Traumatic injuries are often the result of a sudden event, stumbles, tackles, falls or collisions, whereas overuse injuries are related to repetitive stress on the musculoskeletal system with insufficient time to recover. Thus, the explanation of this result could be that a better balance reflected as performance in sway, is an indication of a better overall coordination of the musculoskeletal system. Potentially this benefits the bone and tendon components because of less stress on the musculoskeletal system in the outer positions. Furthermore, the postural control could be even more important to avoid excessive stress on the apophyses. However, the results of the other sway tests pointed in different directions, so this could also be a chance finding.

High skill level a risk factor for injury

The results of the analyses of shuttle run, prone bridge and side-bridge pointed in the direction of the better the performance, the higher risk of overuse injuries. This is not in line with the above reasoning, suggesting good performance in FMP tests and good postural control to be protective of injuries, unless the tests mentioned above expresses other parts of motor performance than shuttle run and prone bridge or unless risk factors for overuse injuries are different from those of traumatic injuries.

The finding that children with the highest levels of motor performance are more likely to have overuse injuries could be explained by the hypothesis that children with high levels of FMP are also the most active children, thus exposing themselves more often and for longer duration in physical activities and leisure time sports increasing the load on the musculoskeletal system. This could be an explanantion as physeal stress injuries are thought to develop when repetitive loading of the extremity disrupts metaphyseal perfusion(160). Furthermore, high-skilled and low-skilled sports participants could be different in behaviour while performing sports. The high-skilled sports participants may have a higher frequency of high-load movements such as acceleration, deceleration or high impact landings in e.g. handball or tumbling gymnastics increasing the physiologic strain on the musculoskeletal system, especially the apophyses. This is for future research to examine.

Methodological considerations

Previous injury

The analyses were performed both adjusted and unadjusted for previous injury. Previous injury is well established as a risk factor for traumatic injury of the ankle (64). However, a recent study on data from the CHAMPS Study-DK showed no association between previous injuries and present injury prevalence and incidence in this population (43). When looking at FMP as predictor of injuries it seems uncertain if the FMP level before the first injury could predict the risk of the first injury. The results indicate, that if the participants had an injury before the FMP tests, the injury should be adjusted for, as previous injury affected both the estimates and the significance. Furthermore, in the current study previous injury was significantly related to the risk of traumatic injury, thus previous injury was a confounder. But as we are not aware of the performance of the participants before their first injury, we cannot establish the true causality between performance measures and injury risk, which means, that we do not know if the most correct result is from the adjusted or un-adjusted analyses. In other words, it is still unknown if the first time an injury occurs relate to poor performance, a frailty in the individual participant or other reasons.

In future studies we suggest to take previous injury into account when analysing risk factors for traumatic injuries in child populations.

Longitudinal associations between motor performance and physical activity (Paper III)

This study explored the longitudinal relationship between objectively assessed FMP and mean MVPA per day in 6-12-year old children. A clear positive and significant association was evident between baseline FMP and mean MVPA per day at three-year follow-up for the Andersen test, vertical jump, shuttle run, handgrip, the Z-score of health-related fitness and the Z-score of performance-related fitness in both boys and girls. Interaction by sex was observed for several FMP components. In the analyses affected by interaction by sex, there was a tendency toward stronger associations between FMP components and PA for boys than girls, and the differences between boys and girls were statistically significant (Table 4).

The clinical importance of the findings primarily depends on the estimated effect sizes - a significant result is not by definition an important result. In order to assist the interpretation of effect sizes, the change in mean MVPA per day resulting from a change of 1 SD in selected FMP measures was calculated. For boys, an increase in the Andersen test from a mean value of 968 m to a 1 SD better result (1070 m) increased the mean MVPA per day with 0.87 percentage points. This is equivalent to an increase of 6.9 minutes spent in MVPA per day (from 61.7 minutes to 69.4 minutes) or an increase of 54 minutes of MVPA per week. Correspondingly, girls improved their mean MVPA by 0.27 percentage points, equivalent to 16 minutes per week, due to a significant interaction by sex.

For the shuttle run, a decrease of 1 SD (2.6 sec) in running time for boys was related to an increase in mean MVPA per day of 6.0 minutes per day or 42 minutes per week. These changes in MVPA seem modest considering the relatively large assumed change in FMP of 1 SD. However, some degree of random measurement error should be expected in this type of study causing us to underestimate the true strength of the association studied.

The clinical implication also depends on the potential to improve performance of the exposure variables. Intervention studies have shown that children respond to training by improving their performance between 6 and 16% (66, 67, 161, 162). Thus, an increase in the Andersen test from 968m to 1070m is possible as it is equivalent to an increase of 10%.

We did not identify studies quantifying the clinical implications of their findings. Consequently it was not possible to compare the clinical implications of the current study to those of earlier studies.

Methodological considerations

Although the methods differ, the positive longitudinal associations between motor performance and PA are in line with results from longitudinal studies using self-report to measure PA (1, 12, 14) and a study on associations between cardio respiratory fitness and PA using objective methods (13). The effect sizes between studies are not directly comparable, as previous studies estimated risk ratios instead of regression coefficients (1, 12, 14) or defined PA differently (13). Furthermore, the positive association found in the study by Barnett el al. (1) was limited to object control only, which was not measured in the current study.

Many different definitions of motor performance exist, as do methods for assessing motor performance. Some studies used fundamental movement skills or motor skills, evaluated by process oriented tests, or tests of coordination, balance and speed of a sequence of motor tasks (1, 12, 163). Other studies examined motor performance as physical fitness, measured by power, strength, agility and cardiovascular fitness (12-14). Moreover, the vast majority of earlier studies on the association between FMP and PA have relied on self-report measures of PA, which further limits the comparability between studies. Therefore the implications of the previous results are not clear. But as the associations of the current study are also positive, this study supports the hypothesis that FMP is significantly related to PA longitudinally. Furthermore, despite different tests, the findings of the current study are in line with previous studies suggesting that motor performance in general is predictive of PA in longitudinal studies (1, 12, 14) and positively associated with PA in cross-sectional studies (3, 4, 8, 9).

Comparison of the coefficients of the analyses with interaction indicated differences in movement behavior between boys and girls. This is supported by previous studies reporting motor skills to be particularly important in boys in relation to PA (164, 165). The reason for this difference between boys and girls is not clear, but perhaps it relates to behavioral differences where girls have a tendency to focus more on the social aspects of sports whereas boys tend to focus on the competitive element in sports (7, 166).

The intensity of PA has been referred to as a predictor of cardiovascular fitness in children (167). The interrelationship between PA and the cardiorespiratory component of motor performance generates the question as to whether motor performance is a predictor of PA or if PA is a predictor of motor performance. Post hoc analyses with mean MVPA per day as a predictor of FMP was performed for three FMP tests (shuttle run, vertical jump and Andersen test) to examine the reverse pathway, including 768 participants. These analyses showed significant associations between mean MVPA per day and the Andersen test (β=3.90, 95% CI= 0.91 to 6.82), and mean MVPA and the shuttle run (β=-0.08, 95% CI=-0.13 to -0.02) at three-year follow up. This result was not in line with a study by Baquet et al. (149) who investigated PA as a predictor of FMP (149), using similar methods for assessing FMP as in the current study, and assessed PA by self-report. Their study reported no significant relation between PA and FMP, maybe due to the use of self-report measures of PA instead of objective measures of PA. One SD change in mean MVPA per day corresponded to a 0.2 seconds change in the shuttle run and an 8 meter longer run in the Andersen test, which do not seem clinically relevant. Thus, the relationship between FMP and PA seemed to differ according to choice of predictor. It could seem that the clinical importance of FMP as a predictor of PA is greater than the importance of PA as a predictor of FMP. However, the random measurement error might be higher for PA compared to FMP, and this could affect the slope coefficient, thus making the above finding less certain (168). Furthermore, previous studies mentioned a possible positive feedback loop between FMP and PA meaning that interventions with PA will result in higher levels of FMP and vice versa (169, 170). Thus, the causal relationship between FMP and PA is still undetermined.

Compared to other potential predictors of PA examined in earlier longitudinal studies, such as self-perception of sports competency, having active parents and influence by behavioral factors (14), the results of the current study indicate that FMP, and in particular running abilities, could be considered among the predictors, which at this point have shown strongest associations with PA.

Limitations

Loss to follow up is known to introduce bias in longitudinal studies if the participants lost to follow up differ from those who remain. The CHAMPS Study-DK is an open cohort study with the possibility to drop-in or drop-out at any time e.g. as new children entered the participating schools. The study most affected by loss to follow-up (paper II) had close to the same number of children carrying the accelerometer at follow-up as at baseline (1171 vs. 1134). But even though approximately the same number of children carried the accelerometers at baseline and at follow-up we experienced a high number of children missing some of the data, resulting in 673 children or 58.7% having all data needed for analyses. Sensitivity analysis on anthropometrics showed significant differences between the included participants and the participants with missing on PA measures. The participants with missing on PA measures were older, and this way apparently also taller and heavier, had higher mean BMI and had significantly higher levels of pubertal development. FMP between the included participants and those excluded due to missing PA measures did not differ, except for handgrip where the excluded participants performed better. This is perhaps a consequence of the age differences, resulting in the excluded participants being older and thus also stronger. The differences between the included and the excluded participants might be a limitation of this study, as we do not know if the association between FMP and PA differed between these groups.

As the CHAMPS Study-DK is conducted as a natural experiment, the selection of the participating schools was not random. The schools volunteered to participate. This could potentially limit the generalizability of the results.

The static balance is only one component of balance (82, 92). Thus, the reported importance of a good balance measured as performance in sway tests, is only reflecting the importance of the static component of balance, and may not be generalized to the total concept of balance as dynamic tests were not included.

The estimates of the sway analyses might be affected by the large intra-subject variability between trials (157) leading to less consistent performance leading to smaller effect sizes or maybe insignificant results, and perhaps related to un-mature motor development. But since all data pointed in the same direction, although some are non-significant, it is anticipated that there is a clear relationship between sway performance and injury risk in children.

The analyses in paper II were not controlled for sports type and intensity during sports, which are both important extrinsic risk factors of injuries. This could bias the result as certain sports types have higher IRR for traumatic injuries than other sports types (142) and could lead to certain types of injuries, thus it could be the sports type acting as a predictor, not the performance test. However, to our knowledge it is not known whether the participants with the best performance in the FMP tests are participating in specific sports types. Future research could take these variables into account.

There are risks of residual confounding due to unknown or unmeasured variables. E.g. in paper III residual confounding could be due to lack of information on other variables shown to be relevant when examining factors associated with PA, such as behavior and psychosocial factors as friends' behavior, parents' behavior, support and heredity (7).

Strengths

The main strengths of this thesis are the longitudinal design, the large sample sizes of each paper, and the use of motor performance tests, with satisfactory reproducibility and validity in child populations (95, 107). In addition, the use of objective measures of PA and the inclusion of an objective measure of static balance by the NWB were strengths. The high degree of feasibility makes it possible to use the NWB not only as a measurement tool in sports clinics, but also as a new tool to use in field studies and larger cohort studies, with the need for an objective measure of a static balance component. To our knowledge this thesis is the first to report sway performance in children measured by field-tests and it is the first study to examine if sway performance in children can predict injury. Furthermore, to our knowledge FMP tests as risk factors for overuse injuries has not been examined previously.

The registration of complaints by SMS-track allowed us to have a frequent and very thorough registration of injuries, including both traumatic and overuse injuries and with limited risk of recall bias due to the weekly registrations by SMS-track, followed by examination and diagnosis within a fortnight. Other studies defined an injury to be present when the participant missed a training or a match or reduced the level of sports activity due to the injury (69, 73), or only registered injuries by medical records or questionnaire (63). Thus, the current study may have a more thorough and complete registration of injuries, which also led to the possibility of adjusting for previous injury. In particular this method led to inclusion of both traumatic and overuse injuries with limited risk of bias due to inaccurate memory or recall bias.

Compared to children not participating in organized sports, the children who do participate in organized sports have higher risk of getting injured (43). The children not participating in organized sports could be the children with the lowest levels of motor performance. If motor performance is a true predictor of injury, this could affect the associations between motor performance and injury risk as the children with the lowest level of FMP did not achieve the same amount of exposure time, thus maybe did not get an injury. Even that we adjusted for sports participation this issue might affect the results, in underestimating the association.

The current thesis tried to quantify the clinical relevance of the significant findings of paper III, but we did not identify other studies in this field of health science and age group that estimated the clinical implication of their finding. Future longitudinal studies should discuss the clinical implication of their findings.

Thus, this study is unique as it has added knowledge on possible predictors of physical activity and physical activity related injuries in children.

Conclusions

Reproducibility and concurrent validity study (Paper I)

Both NWB and AMTI have satisfactory reproducibility for testing static balance tests in a child population. Concurrent validity of the NWB was satisfactory when compared to the AMTI. The NWB appears to be a reliable and valid low-cost tool that could replace the AMTI in field settings and in larger cohort studies including children. Future studies are needed to examine intra-subject variability and to test the predictive validity of NWB in a child population.

Motor performance as predictor of injuries (Paper II)

Several FMP tests were significant predictors of traumatic and overuse injuries. Sway performance was a consistent predictor of traumatic injury in children, in particular traumatic injury of the ankle region. Previous injury affected the estimates in the direction of smaller IRR and fewer significant results. However the causality between present injury, previous injury and performance tests is for future studies to determine.

It seems that for FMP tests the direction of the IRR differed between tests. For traumatic injury the results indicated that poor performance increase the risk of injury (sway performance) or good performance to be protective of injury (single leg hop for distance). For overuse injury the results indicated good performance to increase the risk of injury (static core stability and shuttle run). Thus, risk factors for injuries might differ between traumatic and overuse injuries. More studies are needed to consolidate the findings and to clarify the importance of different performance tests on different types of injuries.

Injury risk might be influenced by behaviour during sports and exposure-time and frequency.

Longitudinal associations between motor performance and physical activity (Paper III)

Cardiorespiratory fitness, shuttle run, vertical jump, health-related fitness and performance-related fitness were significantly associated with time spent in moderate to vigorous physical activity at three-year follow-up. The clinical relevance of the results indicates that good performance in the tests of cardiorespiratory fitness and shuttle run in childhood are important for the amount of MVPA in adolescence, and perhaps most importantly in boys.

Perspectives

The present thesis investigated if field based measures of FMP were longitudinally associated to PA and injuries in children. We suggest, that the gain from the present study is a broader insight into possible modifiable predictors of physical activity and physical activity related injuries in children. With regards to injuries, the evidence build in this thesis was strong in relation to prediction of traumatic injuries in the ankle region. Having adequate balance ability was shown to be important to prevent traumatic injuries, thus balance tests from the NWB could help to identify the children in need to train balance ability. Thus, measuring balance, e.g. on the NWB, could be a possible screening tool to use to identify the children in risk of getting a traumatic ankle injury. However, in order to identify the children at risk, norm values of sway for children at different age groups should be established, and it is necessary to examine if the risk of getting injured is truly linear or if there is a threshold at which the injury risk increase or decrease at a higher rate. A previous study examined if balance and vertical jump was possible to improve by training in 10 to 11 years old children and concluded that training led to improvements in both skills (171). Thus, an intervention to improve balance would probably have an effect and might decrease the risk of traumatic injuries, in particular in the ankle region.

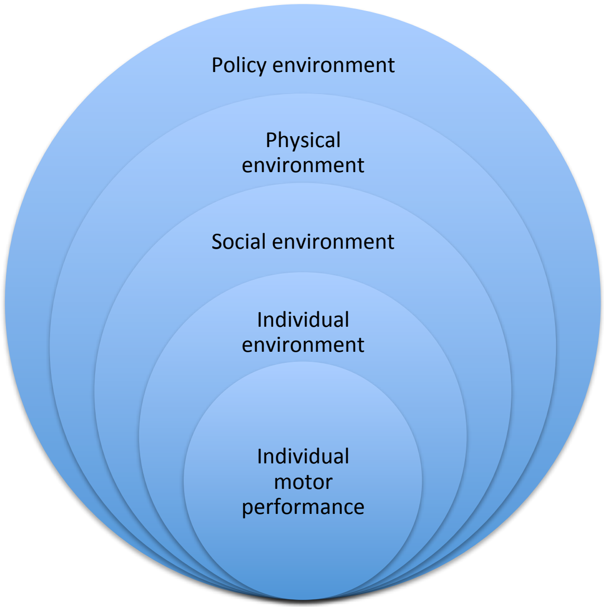
In the injury prediction study of the current thesis, motor performance measures were only measured once. That means that the outcome variable is assumed to be relatively stable. But as proposed by Meuwisse et al (59), the performance profile may change over time. Some children could increase their performance level during the season, some could decrease their performance level and some could remain stable. Future studies investigating if changes in motor performance have an impact on injury risk should measure motor performance and growth in more frequent intervals to take this issue into account, frequencies depending on the possibilities to improve performance. This could elaborate the knowledge on the causal pathway between motor performance measures and injuries in maturing children.

This thesis generates new questions, e.g. if certain skills are more important than others. When running skills result in the rather convincing estimates, should interventions encourage children to practice shuttle run or vertical jump as single skills? Moreover, from my point of view it underlines the importance of getting our children to move with variation during childhood. A hypothesis could be, that the relationship between motor competence, motor performance and PA is like a positive feed-back loop: Moving with variation creates experience in moving, experience in moving creates improvements in motor competence and differentiated skills of motor performance and a feeling of mastery. The feeling of mastery of movement creates more motivation to move, which might increase PA level. Increasing PA level creates variation and experience in motor competence and so on. Thus, well coordinated movements might be the underlying reason of the results showing that running abilities are important skills to achieve in childhood, because, if the underlying skills are not good enough, the more advanced skills as running and jumping might not develop as well. Thus when mastering movement, children feel competent, gain motivation to be active, which will increase PA level later in childhood / adolescence.

The results showing that motor performance is important for future PA, generates the questions of how to influence motor performance, and in what setting an intervention should be performed. The level of motor performance in children is influenced by a wide variety of factors, e.g. anthropometric variables such as body composition, and environmental factors such as training opportunities, family behaviour, motivation, gender. Considering the evidence so far, perhaps the two most important factors are pubertal stage and age (5).

It has not been possible to identify a conceptual model of motor performance, but a suggested conceptual framework could be the ecological framework expressing motor performance to be influenced by different levels in relation to the single individual. Inspired by the ecological model of physical activity (7), a suggestion of an ecological model of motor performance is shown in Figure 8. This model reflects that the individual level, the social level, the physical environment level and the societal/policy level interact between levels and influence an individual behaviour e.g. motor performance. Thus, if this model can be used as a conceptual model of motor performance, the level of motor performance in children will be influenced by a wide variety of factors, such as height, weight and body composition, motivation and gender (individual environment), family behaviour (social environment), training opportunities (physical environment) and, e.g. interventions on community level (societal level) on motor performance.

Figure 8 Suggested ecological framework for motor performance



The theory of the ecological framework generates the hypothesis, that interventions with motor performance training could improve motor performance levels and thereby increase PA levels during childhood and into adolescence. Intervening with motor performance enhancing activity could be one way to make children more competent and more confident when being physically active thereby improving their motivation and willingness to participate in physical activity.

From the CHAMPS Study-DK intervening with extra PE lessons on the community level was successful, as an intervention on this level resulted in preventing overweight and obesity and reducing the cardiovascular disease risk factors in children (172, 173). Especially in the children at most need, e.g. the adipose children. It could be interesting to see if this was also the case for motor performance enhancing interventions. A possible intervention could take place in different settings, e.g. schools, kindergartens and sports clubs. It might be important to perform interventions on motor performance early in childhood, in kindergarten and / or in the first years of school, as the learning potential is high in childhood, and as motor skills seems to track through childhood (6, 174). As motor performance is closely linked to motor skills, and especially in younger ages, an intervention should probably cover both aspects.

It is well known that physical activity is health enhancing in relation to metabolic diseases as type 2 diabetes and the metabolic syndrome (175). Promoting physical activity aims to gain health benefits, but what about the risks of being physically active? What are the risks of increasing the PA level? In a recent editorial, Verhagen et al. (176) opens the discussions on the importance to be aware of the adverse effects of PA. Interventions to increase motor performance in children, with the aim to increase PA, could have an adverse effect by increasing physical activity related injuries. In particular, if children increase their PA by participation in organized sports or leisure time PA as this is the arena of highest risk of sustaining an injury (43, 142). An important target of PA interventions is to increase PA level in the group of least active persons. But as increasing the PA level might increase the risk of injuries, in particular among in the least actives and those starting up PA activities (177), awareness of injury prevention strategies are important in interventions aiming to improve motor performance and physical activity.

Making interventions to increase the PA level accomplish many more benefits than adverse effects though, thus the suggestion still is to generate understanding of how to increase PA level in children and youth and how to make successful interventions to increase PA level with the overall aim to achieve health benefits. And hopefully by appropriate interventions paying attention the possible drawbacks of increasing PA.

Summary in English

The importance of motor performance in relation to physical activity, has primarily been examined in cross sectional studies. The studies of the importance of motor performance in relation to injuries has primarily included traumatic injuries, and so far we did not identify studies examining balance, measured as postural sway, as a risk factor of injuries in children.

The use of a force platform to assess balance (postural sway), is frequent in laboratory settings but not in field settings. The force platform technique to measure sway provides clinicians and researchers with a valuable objective measure of balance, potentially capable of predicting injuries. Thus, the current project aimed to include an objective measure of balance with no ceiling effect or age limitations. We identified a proper equipment to measure sway, the Nintendo Wii Board, but the equipment was only tested for reliability and validity in adult populations and in laboratory settings. The current thesis used objective measures of motor performance.

This thesis was based upon three studies, and the data were obtained from The Childhood Health, Activity and Motor Performance School Study, Denmark. The number of participants in the studies varies depending on the purposes, from 58 to 1244 participants.

1. Study I evaluated the reproducibility and the validity of the Nintendo Wii Board when used in a field setting. The concurrent validity was evaluated by comparing the Nintendo Wii Board to the AMTI platform. Participants were aged 10 to 14 years old.
2. Study III evaluated if motor performance tests, including sway measures, were predictors of traumatic and / or overuse injuries in children aged 10 to 15 year olds.
3. Study II evaluated if motor performance measures in 6 to 10 year olds were predictors of physical activity at three years follow-up

In study I we found the reproducibility and validity of the Nintendo Wii Board satisfying. This led to inclusion of the Nintendo Wii Board as a measurement tool to evaluate postural sway on the participants.

The main findings in study II were that several motor performance tests were significant predictors of traumatic or overuse injuries. The importance of the single motor performance items seemed to differ depending on whether the outcome was traumatic injuries or overuse injuries. For traumatic injuries poor sway performance significantly increased the risk of traumatic injuries, in particular in the ankle region. Good performance in single leg hop for distance was protective of traumatic knee injuries. For overuse injuries good performance in shuttle run and core stability exercises increased the risk of injuries in the knee region.

It seems that the risk factors of overuse injuries are not the same as for traumatic injuries. These findings should be confirmed by future studies.

The main findings in study III was that several motor performance tests were significantly related to moderate to vigorous physical activity at three years follow-up. In particular, good running abilities seemed to be important skills to achieve in childhood to reach higher levels of PA later in childhood / adolescence. The causality, though, still cannot be determined from the current thesis.

Summary in Danish

Det er primært tværsnitsstudier som har undersøgt betydningen af fysisk fitness (motorisk præstation) hos børn, for deres fremtidige fysiske aktivitetsniveau. Motorisk præstation som prædiktor for skader er primært undersøgt i relation til traumatiske skader, og til dato har vi ikke identificeret studier, som har undersøgt betydningen af statisk balance (posturalt sway) for skadesrisikoen hos børn.

Måling af posturalt sway på en kraftplatform anvendes ofte i laboratoriestudier men ikke i feltundersøgelser, og måleredskabet er indtil videre ikke anvendt i studier hvor det er børn der undersøges. Ved at anvende en kraftplatform til at måle posturalt sway, opnår klinikere en værdifuld objektiv registrering af balance, som potentielt kan prædiktere skadesrisiko. Nærværende studie sigtede mod at inkludere et objektivt måleredskab til kvantificering af balancepræstation. Hensigten var at inkludere et måleredskab som ikke blev begrænset af manglende muligheder for forbedret score, eksempelvis på grund af alder. Nintendo Wii platformen har vist sig at være reliabel og valid når platformen testes blandt voksne, men dette er endnu ikke undersøgt blandt børn.

I denne afhandling er de øvrige målinger af motorisk præstation foretaget med objektive tests.

Afhandling er baseret på tre studier, og data er indsamlet i studiet The Childhood Health, Activity and Motor Performance School Study, Denmark, også kaldet Svendborgprojektet. Deltagerantallet i studierne varierer fra 58 til 1244 deltagere.

1. Studie I undersøgte reproducerbarhed og samstemmende validitet af Nintendo Wii platformen. Validiteten blev undersøgt ved at sammenligne resultaterne fra Nintendo Wii platformen med resultater fra en AMTI kraftplatform. Deltagerne var 10-14 årige børn.
2. Studie II undersøgte om motorisk præstation, inklusiv sway målinger fra Nintendo Wii platform, kunne prædiktere skader hos 10-15 årige børn, såvel traumatiske skader som overbelastningsskader.
3. Studie III undersøgte om motorisk præstation hos børn i 6 til 10-års alderen kunne prædiktere fysisk aktivitetsniveau ved tre-års follow-up

Studie I viste, at Nintendo Wii platformen præsterede tilfredsstillende i forhold til såvel reproducerbarhed som validitet når målingerne blev sammenlignet med målinger fra AMTI platformen. Derfor blev Nintendo Wii platformen inkluderet som måleredskab til målinger af posturalt sway hos deltagerne i studie II.

I studie II fandt vi adskillige motoriske præstationstests som var signifikante prædiktorer for traumatiske skader og / eller overbelastningsskader. De enkelte tests så ud til at have forskellig betydning for skades risiko, god præstation var i nogle tests associeret med forøget risiko for skader

mens det for andre tests var associeret til at beskytte mod skader. For traumatiske skader var nedsat postural kontrol en signifikant prædiktor for skader, særligt for ankelskader. God præstation i et-bens længdehop var beskyttende mod traumatiske knæskader. For overbelastningsskader forøgede god præstation i pendulløb og core-stabilitets tests risikoen for overbelastningsskader i knæene. Resultaterne tyder på, at risikofaktorer for overbelastningsskader og traumatiske skader er forskellige, hvilket stemmer godt overens med, at skadestyperne har forskellige skadesmekanismer.
Resultaterne fra denne afhandling bør bekræftes af fremtidige studier for at etablere viden om mulige prædiktorer samt opnå mere viden omkring kausaliteten mellem skader og motorisk præstation.
I studie III fandt vi at adskillige motoriske tests var signifikant associeret til moderat til høj fysisk aktivitet ved tre års follow-up. Resultaterne tyder på at det er særlig vigtigt for fremtidigt aktivitetsniveau at præstere godt i løbe aktiviteter i barndommen. Kausaliteten mellem motorisk præstation og fysisk aktivitet kan dog ikke afgøres i nærværende studie.

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Paper I

Paper II

Paper III