ASSOCIATION OF BODY COMPOSITION, PHYSICAL ACTIVITY AND FRACTURE HISTORY ON POSTURAL SWAY IN GIRLS

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Master's Thesis in Physiotherapy
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Spring 2012

ABSTRACT

Tiina Aarnio: Association of body composition, physical activity and fracture history on postural sway in girls.
University of Jyväskylä, Department of Sport and Health Sciences, spring 2012.
Master's Thesis in Physiotherapy 60 pages.
Supervisors: Professor Sulin Cheng (University of Jyväskylä), Professor Ari Heinonen (University of Jyväskylä).

Proper balance control is essential for normal everyday activities. High body sway is related to poor postural balance and a risk of falling with possible fractures. Studies of the impact of body mass index, fat mass, lower limb strength and physical activity on postural control in normal adolescent population are scarce. The purpose of this study was to investigate whether previous fracture history during growth, body composition, lower limb strength, leisure time physical activity and inactivity level (PIA) are associated with body sway in adolescent population.

The study participants consisted of 212 girls (mean age 18.6±1.1 yrs) who lived in the city of Jyväskylä and its surroundings. Postural sway in antero-posterior (AP, mm/s), medio-lateral (ML, mm/s) and velocity moment (VM, mm^2/s) was measured with a force plate in four different static standing positions: bi-pedal; open eyes (OE) and closed eyes (CE), and semi-tandem; left foot in front (STL) and right foot in front (STR). Lower limb strength was measured with maximal isometric quadriceps test (MaxKE) and vertical squat jump. Lean mass (LM) and fat mass (FM) were assessed by DXA. The girls were divided first into two groups according to the incidence of fracture; No Fracture (NF, n=161), Fracture (F, n=51). In addition, three groups were formed based on low, medium and high physical activity levels (LTPA). An additional 3-group constellation was formed based on the BMI index (Low, Medium, Ow&Obese). Differences between the fracture groups were analyzed by independent t-test or Mann-Whitney U test. Differences among the three LTPA groups and differences among the three BMI groups were analyzed by one-way ANOVA or Kruskal-Wallis ANOVA. Regression analysis was conducted to assess whether fracture, anthropometric variables and physical activity are associated with body sway.

No significant systematic differences were found in body sway between fracture groups, even though the F group had smaller VM-OE (p=0.003) and AP-CE (p=0.042) than the NF group. The F group had on average one hour more in sitting and lying down position a day than the NF group. No significant differences in body sway were found between the LTPA groups or the BMI groups. LTPA groups differed significantly in their LTPA score (p=<0.001). The girls in the high LTPA group were taller and had a lower FM% and more LM than the Medium and Low LTPA groups (p=0.038, p=0.009, p<0.001, respectively). They also could jump higher than other LTPA groups (p=0.001). Regression analysis revealed that MaxKE made a small but significant adverse contribution to ML-OE (β=-0.22), VM-OE (β=-0.21) and ML-CE (β=-0.15).

In summary, body sway, measured in static standing positions, is not associated with previous fracture history, body composition or physical activity. However, lower limb strength is associated with body sway indicating the importance of lower limb strength in postural stability in adolescent population.

Keywords adolescent, girls, postural balance, sway, knee extensor strength, BMI, Fat Mass, Lean Mass, fractures, LTPA

TIIVISTELMÄ

Tiina Aarnio: Kehon koostumuksen, liikunta-aktiivisuuden ja lapsuusajan murtumien yhteys vartalon huojuntaan.
Jyväskylän Yliopisto, Liikunta- ja terveystieteen laitos, kevät 2012.
Fysioterapian Pro-gradu tutkielma 60 sivua.
Ohjaajat: Professori Sulin Cheng (Jyväskylän yliopisto), Professori Ari Heinonen (Jyväskylän yliopisto).

Hyvä tasapainon hallinta on tärkeää normaalien päivittäisten askareiden suorittamiseksi. Nuorten tasapainotutkimuksia löytyy vain vähän. Tämän työn tarkoituksena oli tutkia, voiko lapsuus- ja nuoruusiän murtumilla ja vartalon huojunnalla aikuisuuden kynnyksellä olla yhteys, ja onko fyysisellä aktiivisuudella, alaraajan voimalla ja kehon koostumuksella yhteys vartalon huojuntaan.

Kaikkiaan 212 Jyväskylän seudulla asuvaa tyttöä (keskimääräinen ikä 18.6±1.1) osallistui tutkimukseen. Vartalon huojuntaa mitattiin voimalevyllä, kehon koostumus mitattiin sekä konventionaalisesti että DXA-laitteella, ja alaraajan voima mitattiin maksimaalisella isometrisellä polven ojennustestillä sekä vauhdittomalla vertikaalihypyllä. Liikunta-aktiivisuutta tutkittiin kyselytutkimuksella. Tytöt jaettiin ensin kahteen murtumaryhmään (NF= ei murtumaa, F= murtuma). Eroja ryhmien välillä tutkittiin riippumattomalla t-testillä tai Mann-Whitneyn U-testillä. Kolme ryhmää muodostettiin myös liikunta-aktiivisuuden (LTPA) mukaan (High, Medium, Low) sekä kolme ryhmää kehon koostumuksen (BMI) mukaan (Lean, Normal, OW&Obese). Liikunta-aktiivisuusryhmien ja kehon koostumusryhmien välisiä eroja analysoitiin varianssianalyysillä. Regressioanalyysin avulla pyrittiin selvittämään, voiko lapsuusiän murtumilla, kehon koostumuksella ja liikunta-aktiivisuudella olla yhteys kehon huojuntaan.

Tutkimustulosten perusteella ei löytynyt merkitseviä eroja kehon huojunnassa liikunta-aktiivisuusryhmissä eikä kehon koostumusryhmissä. F-ryhmän vauhtimomentti silmät auki testissä ja eteen-taakse huojunta silmät kiinni oli pienempi kuin NF-ryhmän ($p=0.003$, $p=0.042$, vastaavasti). F-ryhmä vietti yhden tunnin enemmän päivässä istumiseen ja makaamiseen kuin NF-ryhmä. Aktiivisimman liikuntaryhmän tytöt olivat pidempiä, heillä oli alempi kehon rasvaprosentti ja korkeampi rasvattoman kudoksen määrä kuin muissa ryhmissä ($p=0.038$, $p=0.009$, $p<0.001$), vastaavasti. He myös pystyivät hyppäämään korkeammalle kuin muiden ryhmien tytöt ($p=0.001$). Regressioanalyysi osoitti, että alaraajan ojennusvoimalla oli merkitsevä, vaikkakin heikko negatiivinen yhteys sivusuuntaiseen huojuntaan ja vauhtimomenttiin bi-pedaaliasennossa silmät auki ($\beta=-0.22$ ja $\beta=-0.21$, vastaavasti) ja silmät kiinni asennoissa ($\beta=-0.15$).

Yhteenvetona voidaan todeta, että merkitsevää yhteyttä huojunnan ja kehon koostumuksen, liikunta-aktiivisuuden tai murtumaryhmien välillä ei löytynyt. Alaraajan ojennusvoiman negatiivinen yhteys huojuntanopeuteen viittaa kuitenkin alaraajalihasten voiman tärkeyteen asennonhallinnassa myös nuorilla henkilöillä.

Asiasanat nuoret, tytöt, tasapaino, huojunta, polven ojennusvoima, kehon koostumus, murtumat, liikunta.

PREFACE AND ACKNOWLEDGEMENTS

This master’s thesis was part of a large longitudinal study (CALEX Family Study – Determinants of growth and body composition in girls: an 8-year follow-up study) led by Professor Sulin Cheng at the Department of Health Sciences, University of Jyväskylä.

In this study, I selected the research questions, participated in data collection of the postural sway and body composition measurements, did the statistical analysis of the results and wrote the thesis.

Firstly, my sincerest thanks to my supervisor Professor Sulin Cheng for her patient and encouraging guidance in my learning process, and her never-ending and contagious enthusiasm in research. I feel very privileged to have been working in a very international and active research team. I am truly indebted to my dear friend and study colleague Eszter Völgyi, PhD, for teaching me statistics and helping me with my study analyses, and generously housing me whenever I visited Jyväskylä. My special thanks go to Shu Mei Cheng, LicVet, for all her work and endless hours of preparing the data in the study, and always finding time to help me with my problems of data handling. I would like to thank Arja Lyytikäinen, MSc, for her friendly help whatever questions I would have. My sincere thanks go to Professor Ari Heinonen for reviewing my thesis.

I also wish to extend my warmest thanks to all the participants and research staff in the study.

Jyväskylä, 14th March 2012

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ABBREVIATIONS

AP	Antero-Posterior
BMD	Bone Mineral Density
BOS	Base of Support
CE	Closed Eyes
cm	centimeter
CNS	Central Nervous System
COG	Center of Gravity
COM	Center of Mass
COP	Center of Pressure
F	Fracture Group
KEMax	Knee Extensor Strength
Kg	Kilogram
m	Meter
ML	Medio-Lateral
mm	Millimeter
N	Newton
NF	No-Fracture Group
LTPA	Leisure Time Physical Activity
OE	Open Eyes
PIA	Physical Inactivity
s	Second
VMOE	Velocity Moment Open Eyes
VMCE	Velocity moment Closed Eyes
VMSTL	Velocity moment Semi-Tandem Left
VMSTR	Velocity moment Semi-Tandem Right

CONTENTS

1 INTRODUCTION

Good postural stability is needed for all normal daily activities. Proper balance control is critical in falls prevention in every age group. Adults with high postural sway are known to fall more often and have a higher risk for bone fracture (Sihvonen 2004). The falls and subsequent fractures are not only a tragedy for the individual himself but cause a significant burden to the society as well.

Active children and young adolescents fall frequently during growing up and often the result from a fall is a fracture. Though it is difficult and perhaps unnecessary to document a youngster's every fall (Landin 1983, Shumway-Cook, Woollacott 2001, Goulding et al. 2000), early detection of disturbances in balance capabilities in children and adolescents is of paramount importance (Clark, Ness & Tobias 2008, Cheng et al. 2009). Diagnosis and proper balance training intervention may help correct the postural stability deficits and safeguard for future falls.

Modern technologies have brought with them an inactive life style that has affected children's and adolescents' physical activity levels with fewer young being very active and a large population settling into sedative television viewing and computer playing (Stettler 2000). In addition, youngsters and adults eat foods that contain high amounts of fat and carbohydrates which in turn have resulted in a population of overweight and obese children and adults (Helakorpi et al. 2008). Studies of the association of weight on postural balance suggest that obesity has a deleterious effect on postural stability (Bernard et al. 2003).

The purpose of this study was to investigate whether previous fracture history during growth, body composition, lower limb strength, leisure time physical activity (LTPA) and inactivity (PIA) are associated with body sway.

2 POSTURAL CONTROL

Postural stability is defined as the ability to maintain the position of the center of body mass (COM), also called the center of gravity (COG), or the net location of the center of mass in vertical direction, within the stability limits i.e. base of support (BOS) (Latash 2008, 211). Postural stability is needed for the dual purposes of standing steadily and moving the body in space in a controlled manner (Winter 1995). Thus stability involves establishing equilibrium between destabilizing and stabilizing forces (Shumway-Cook, Woollacott 1995). Postural orientation involves the ability to maintain the appropriate alignment between the body segments, and between the body and the environment with the aim of maintaining the center of the body mass inside the area of support (Latash 2008, 210).

The terms balance, equilibrium and postural control are often used as synonyms for the same concept related to the mechanism by which the human body prevents itself from falling or losing balance (Nashner, Black & Wall 1982). The velocity and amplitude of the body sway are considered to portray a person’s postural stability, the smaller these sway characteristics, the better the equilibrium (Latash 2008, 210).

2.1 Sensorimotor control of postural stability

The upright posture is a very unstable position. Standing still is never static or rigid. The maintenance of static balance is controlled by the central nervous system without conscious activation of the muscles (Shumway-Cook, Woollacott 2001). Nashner describes human upright posture as a product of a complex dynamic control system that relies on integration of inputs from multimodal sensory sources, including visual, vestibular, proprioceptive and musculo-skeletal systems (Nashner, Black & Wall 1982) counteracting each other and the environmental events acting upon it (Balasubramaniam, Riley & Turvey 2000). Stable posture is thus under an unconscious and, continuous control of sway (Latash 2008, 211, Forssberg, Nashner 1982).

The visual system processes information related to the location of objects in space, the somatosensory system throughout the body informs the CNS about the position and motion of the body in space with reference to the support surfaces and also about the relationship of different body segments to one another. The vestibular systems provide information about the position and motion of the head in respect to gravitational and inertial forces (Horak 2006, Kuo 2005). Challenges to any modalities of the sensorimotor system, such as closing of the eyes or standing with feet in a tandem position, will increase a person's sway, independent of health status, age, training or expertise in postural control (Asseman 2005, Vuillerme et al. 2001).

2.2 Postural sway

A person standing still inevitably sways. Stability limits are the boundaries within which the body can maintain its position without changing the base of support. The ability to maintain a posture, such as balancing in a standing or sitting position, is operationally defined as static balance (Winter et al. 2003).

The underlying explanations for the mechanisms of spontaneous postural sway are still being studied, and so far remain one of the poorly understood phenomena of motor control (Latash 2008, 211, Westcott, Lowes & Richardson 1997). According to one view, sway results from “noise”, random neural control system error and according to the other, sway is the consequence of a purposeful function of the nervous system (Winter et al. 2003, Schmid et al. 2004). According to Maurer and Peterka (2005), balance control results from continuously active feedback control mechanisms (Maurer, Peterka 2005).

The two trajectories of the characteristics of postural sway commonly studied are the body's center of mass (COM) trajectory and the body's center of pressure (COP) trajectory. COP is the point where the resultant force from the support surface is applied to the body and COM is the approximate center of the body mass. In quiet standing the center of pressure (COP) moves slightly ahead but in phase, with the center of body mass (COM) as the body sways spontaneously in an upright position (Winter et al. 2003) within the area of support. This area, in quiet bipedal standing, is equivalent to the area of the feet and the area between them (0.1 m^2). During quiet stance the COP usually shows larger shifts than COM because COM portrays the inertia of the whole body (Latash 2008, 210).

The different characteristics of sway most commonly studied are in the time domain; mean velocity, mean path length per unit time (i.e. mean speed) (Jeka et al. 2004, Prieto 1996) and the area covered with the sway trajectory over a fixed time interval as well as the structure of the sway, usually in antero-posterior and medio-lateral directions, to infer neurological and mechanical mechanisms of postural control (Rietdyk et al. 1999, Le Clair, Riach 1996). In the calculation of the velocity moment, both the velocity of the COP and its actual distance from the center of the test are taken into account and the result is expressed as the mean area covered by the movement of the COP during each second of the test (Good Balance 2004, 21).

2.3 Balance Development

The ability to maintain balance develops during childhood and declines later in life due to normal deterioration processes of the sensory systems as well as various pathologies (Shumway-Cook, Woollacott 1995, Sihvonen, Sipila & Era 2004, Laughton et al. 2003). Infants learn to sit and crawl, creep and walk within the first year of their life. This development involves an amazing array of skill and abilities before the child can control his movements against unexpected perturbations from his environment or misinformation from his own nervous system (Shumway-Cook, Woollacott 1995, Sheridan 1982 reprinted). As growing children and adults engage in more difficult and higher levels of activities, their postural control develops and matures to answer to the changing external perturbations (Bair et al. 2007). Postural control develops nonlinearly with the sensory and motor systems developing in staggered phases, lagging interchangeably at certain points of postural control development before reaching full maturity at young adulthood (Shumway-Cook, Woollacott 1995, Sundermier et al. 2001).

According to literature, children achieve adult-like sensory integration for stable balance around 12 to 14 years old (Shumway-Cook, Woollacott 2001, Assaiante et al. 2005) but according to Peterson et al. (2006) and Steindl et al (2006), the postural strategies of 14 to 15 year old teenagers differ from that of young adults, suggesting that sensory integration is still developing (Steindl et al. 2006, Peterson, Christou & Rosengren 2006). Lebiedowska and Syczewska (2000) found no statistically significant correlation between sway parameters and developmental factors such as body height, body mass and age in their study of children aged 7 to 18 years which may confirm the theory that sensory systems are the main factors in the development of postural stability (Lebiedowska, Syczewska 2000).

The sway amplitude of different age groups can be portrayed as a U-shaped curve: children and old persons showing the largest sway amplitudes, healthy young adults swaying least (Sihvonen, Sipila & Era 2004, Era et al. 2006, Rogind et al. 2003). Balancing abilities begin to deteriorate around 40 years of age, but the speed of the deterioration varies from person to person. There are also differences in sway amplitudes and frequencies between men and women. Men sway more than women portraying larger velocity and total length of COP (Chiari et al. 2002, Nolan, Grigorenko & Thorstensson 2005), and women sway spontaneously at higher frequencies than men. In addition, healthy persons usually sway more in antero-posterior direction than in medio-lateral direction (Era et al. 2006). According to Latash, a person's sway projection in a graph looks like an irregular process of 1 cm or less (Latash 2008, 212).

2.4 Balance Assessment

There are many different laboratory and clinical tests and methods to assess balance abilities and properties of balance. The selection of a suitable method depends on the purpose of the evaluation. In the past decades several laboratory methods have been developed for accurate, objective and reliable measurement of postural equilibrium (Jeka et al. 2004, Era et al. 2006, Nashner 1983).

The laboratory instruments can be divided into three categories according to the physical variables that are of interest for the researcher. 1) Kinematic analysis measures the characteristics of the movement of body segments i.e. motion analysis, describing the linear and angular displacements, velocities and accelerations 2) Electromyography (EMG) measures the bioelectric activity of the muscles, and 3) Kinetic analysis instruments, such as force platforms, measure forces that cause movement including internal and external forces. Internal forces come from muscle activity, joints and ligaments. External forces are caused by the ground or external loads (Latash 2008). In this study, kinetic analysis is used in assessing postural sway.

2.4.1 Kinetic analysis

The force plate system measures and analyses the vertical forces produced by the subject, and projects a plot of the pressure center, i.e. the projection to the ground of the center of gravity. By means of the force transducers the ground reaction vector and its point of application, the center of pressure (COP), can be recorded. Ground reaction forces (the forces under the area of the foot) and COP provide important insights into the process of controlling balance, since they can be directly related to the motion of body center of mass (COM) (Winter 1995, Baratto et al. 2002). Force platform measurement has been found to be a common and reliable technique in the evaluation of body sway in standing balance (Kejonen, Kauranen & Vanharanta 2003, Bauer et al. 2008).

2.4.2 Static and dynamic body sway analysis

Two different experimental paradigms are used in assessing postural sway: static and dynamic posturography. Static posturography or postural steadiness, characterizes the amount of body sway when a subject stands upright as still as possible, referring to the internal mechanisms. Large sway amplitudes and frequencies are considered to represent poor postural balance ability. Dynamic posturography characterizes the performance by measuring the postural response to an applied, external or volitional postural perturbation (Prieto 1996).

In this study the static body sway characteristics were used in the measurements. In test situations the stances are usually changed from an easy, side-by-side-stance, to more complicated positions such as standing on one leg or one leg behind the other.

2.5 Complexity in balance assessment

Postural stability has generally been defined as the ability to stand with as little sway as possible. Yet, even healthy persons without postural impairment can show considerable variability in their postural responses (Geurts, Nienhuis & Mulder 1993, 1993, Benvenuti et al. 1999).

A variety of different characteristics of sway have been suggested as the most accurate measures of good postural steadiness. Velocity, range, amplitude, fractal dimensions and the frequency of sway have commonly been used as outcomes of the posturographic characteristics in studies, but there is a lack of consistency in which of these variables are used for analyses, many studies concentrating on either amplitude or velocity (Bauer et al. 2008, Doyle, Newton & Burnett 2005). According to many recent studies, velocity of sway has been found to be a reliable measure of stability (Jeka et al. 2004, Lin et al. 2008, Abrahamov, Hlavacka 2007, Westlake, Wu & Culham 2007, Lafond et al. 2004). Era and colleagues (2006) have presented normative values of sway velocity for persons over 30 years of age, but normative values for velocity in young, 17 to 21 year old persons have not yet been published (Era et al. 2006).

Measurement time and number of trials may vary in different studies from 10 seconds to more than 300 seconds with one to three trials or more. Doyle et al. recommended up to 60 seconds for trial time with at least five trials (Doyle et al. 2007), Jeka et al executed three 364 second trials in their study, where they concluded that velocity information is the most accurate form of sensory information used by the CNS to stabilize posture during quiet stance (Jeka et al. 2004). In addition, studies have used absolute or averaged values of the tested variables in analysis.

Repeated posturography tests show a high variability between the consequent test trials even in healthy subjects (Corriveau et al. 2004). Hamill and van Emmerick have suggested that traditional perspective, in which variability of sway is often associated with instability and disability, is too limited to reveal the explicit aspects of the sway that are related to a certain condition (Hamill, van Emmerick 2000).

Sampling time as well as cut-off and sampling frequencies vary between studies which may have an effect on the interpretation of the results. According to Schmid et al. (2002) too little attention has been paid to the presentation of the experimental acquisition setting, both before and after the experiment, which may prevent standardization of posturography (Schmid et al. 2002).

According to studies care should be taken when defining experimental protocols of postural sway evaluation as so many threats act upon the postural stability. Body height, body weight, foot placement, and foot width influence postural sway (McIlroy, Maki 1997, Chiari, Rocchi & Cappello 2002). In addition, studies by Conforto et al. (2001) suggest that internal mechanics, such as respiratory and hemodynamics may affect postural stability (Conforto et al. 2001). Also attention and arousal may have an effect on postural sway in a testing situation (Maki, McIlroy 1996).

Studies with certain groups of people have shown that small sway amplitude is not necessarily always the best indicator of good postural stability (Hughes et al. 1996, Lorbach et al. 2007). Blaszczyk et al. (2009) found that obese subjects portrayed a smaller sway than normal weight subjects and suggest that it can be a result of compensatory modification of the excess body weight (Blaszczyk et al. 2009). In contrast, Mc Graw et al. (2000) reported a significant increase in sway in obese subjects (McGraw et al. 2000). Studies have also shown that large sway does not necessarily predict poor balance but rather may manifest that persons who are trained in maintaining balance (i.e. gymnasts, ballet dancers etc) have broader stability limits than non-trained persons (Gerbino, Griffin & Zurakowski 2007b, Calavalle et al. 2008).

Allard et al. (2001), Farenc (2003) and Nolan (2005) among others, report that gender affects a person's sway and thus has to be taken into account when assessing postural sway (Nolan, Grigorenko & Thorstensson 2005, Allard et al. 2001, Farenc, Rougier & Berger 2003). Gender difference has been contributed to women's lower center of gravity, causing them to sway less. Also Baker et al note that the reliability of children's postural sway measurement is influenced by age as well as measurement system (Baker et al. 1998). Nolan et al. (Nolan, Grigorenko & Thorstensson 2005) showed that boys aged 9 to 10 years exhibited a greater COP movement than same age girls, presenting an overall greater variation in their body sway parameters than girls. According to Nolan boys may lag behind in developing postural control, and suggests that postural control in boys and girls should be thus studied separately (Nolan, Grigorenko & Thorstensson 2005). Era et al. confirm that adult males portray a larger sway than women (Era et al. 2006).

2.6 Summary of the balance studies

Rogind et al. note that longitudinal studies of the balance development throughout life span do not exist to this date (Rogind et al. 2003). Not many studies have suggested nominative values for a normal sway in different age groups (Era et al. 2006). There exists a broad variety between experiment set ups and standardized protocols in balance assessment. Common techniques for discriminating standing balance abilities in healthy, young population are needed (Gerbino, Griffin & Zurakowski 2007a). Nevertheless, studies are in agreement that persons with large body sway values in any sway- related characteristics represent poor postural stability.

3 FRACTURE STUDIES

3.1 Fracture etiology

Adolescent injuries are an important public health problem worldwide (Towner, Errington 2004, Khosla et al. 2003). On average, about 25 % of children are injured each year (Landin 1983, Walsh et al. 1996). About one third of all children suffer at least one fracture before the age of 17, and 25 to 30 % of all adolescent fractures occur in the upper limb, mainly through the distal end of the radius and ulna (Bailey et al. 1989, Cooper et al. 2004). Leisure time and sports activities play a major role in children's and adolescents' injury incidence. Falling from a modest height or losing one's balance are the most common reasons for a fracture. Mattila et al. (2004) reported that most unintentional injuries among 12 to 18 years old Finnish boys and girls occurred during leisure time sports activities, and one third of all needing medical treatment were sport-related (Mattila et al. 2004), which is in concordance with international studies by Bailey et al. (1989) and Fardellone (Bailey et al. 1989, Fardellone 2008).

Presently many studies about fractures and bone properties in children and adolescents can be found, but studies about fractures and postural balance are scarce. Bone strength and bone mineral density (BMD) are only one determinant of fracture risk when a fall occurs; the direction, the force of the impact on bone and the muscular coordination and muscle strength to lessen the impact also determine whether a fracture occurs (Cheung & Detsky 2008). Cheung and Detsky (2008) comment also that the fracture is an end product of losing stability. Therefore the reasons behind losing one's balance and the interventions and preventive actions not to do so are important in fracture prevention, not just the bone quality (Cheung, Detsky 2008). Adequate postural control to avoid injury is essential to all, especially to people with deficits in bone properties, whether they are young or old. Still, the epidemiology of fractures is poorly studied (Khosla et al. 2003, Walsh et al. 1996).

3.2 Fracture incidence

The incidence of all fractures in children peaks between the ages of ten and fourteen which parallels the time of peak pubertal growth spurt (i.e. 11 years of age in girls and 14 years of age in boys) (Landin 1983, Cooper et al. 2004). It has been suggested that fracture incidence coincides with an increase in physical activity levels of children and adolescents, representing a transient imbalance between physical activity, physical growth and acquisition of bone mass (Bailey et al. 1989, Parfitt 1994). However, several studies, including a WHO study of physical activity in school aged children reports that physical activity actually tends to decrease between the ages 11 and 15, contradicting the increase in fracture rates to be caused by an increase in physical activity (Roberts, Tynjälä & Komkov 2004). In addition, Ma (2003) reported interestingly, that there was a positive association between upper limb fractures and TV, computer and video viewing, as well as with sports participation with the difference that in girls' sports participation had a protective effect. They also found that light physical activity was protective of fractures (Ma 2003) .

Landin (1983) and Mattila (2004) report that the risk of fracture has increased, but the severity of the trauma has decreased, which both researchers conclude, may be a result of better injury prevention, safety regulations and risk awareness programs (Landin 1983, Mattila et al. 2004). In their recent study Mäyränpää et al. (2010) found a decrease in the incidence of fractures. Whether it is a result explained by the improvement in injury prevention or just a transient phenomenon, requires further investigation (Mäyränpää, Mäkitie & Kallio 2010).

The incidence of injuries differs between countries (Cooper et al. 2004, Lyons et al. 2000a). The study by Lyons et al. (2000) reports that the Scandinavian children have fewer fracture incidences than for instance children in Wales (16.6/1000 children in Scandinavia from birth to age 14 compared to the Welsh children's 36/1000 fracture rate) (Lyons et al. 2000b).

3.3 Upper limb fractures

Fractures of the distal forearm are extremely common in childhood and adolescence (Khosla et al. 2003), boys suffering from fractures more often than girls (Cheung, Detsky 2008). Khosla et al. (2003) report in their population based study in the US that the incidence of distal forearm fractures in children has increased significantly from 1969 to 2001 matching the results from several other studies (Khosla et al. 2003, Bailey et al. 1989, Lyons et al. 2000b). According to Landin (1983) a risk for fracture in boys from birth to 16 is 42 % and in girls 27% (Landin 1983). Rennie et al. (2007) reported that the incidence of fractures in Edinburgh, Scotland in 2000 was 20.2/1000/year and that 61 % of children's fractures occurred in males. Their study also confirms the upper limb as the most common area of fracture (Rennie et al. 2007).

Wrist fractures frequently result from a modest fall during play and sports (Mattila et al. 2004, Goulding 2007) but it is not known whether children suffering these fractures fall more frequently than those who have no fractures. There is evidence nevertheless that 66% of all fractures during growth occur in children and adolescents who fracture on more than one occasion, suggesting that certain children may be predisposed to fracture (Bailey et al. 1989, Goulding, Grant & Williams 2005). These otherwise healthy children may have been identified as having low bone mineral content and bone mineral density, low bone size and bone accrual (Goulding 2007). Another study by Cheng et al. (2009) found that girls who had sustained a fracture during growing up, had lower bone mass, and were taller than their non fractured counterparts (Cheng et al 2009). A meta-analysis by Kanis et al. (Kanis et al. 2004) and a study by Yeh et al. (Yeh et al. 2006) conclude that previous history of fracture confers an increased risk of a new fracture, which cannot solely be explained by measurement of BMD, but may perhaps be related to other factors such as functional deficits, for instance coordination.

3.4 Studies in fracture and balance

Studies in fracture incidence and postural stability in children and adolescents are scarce. Postural instability in children has been reported to be caused by neurological deficits (Niemensivu 2006) or motor development delays and disorders (Geuze 2005). Goulding and Jones have reported that there exists a group of risk factors for distal forearm fractures in children and adolescent, such as low bone mineral density, physical inactivity, overweight and obesity, dietary habits, genetic factors and poor coordination (Goulding 2007, Goulding, Grant & Williams 2005, Kanis et al. 2004, Yeh et al. 2006, Goulding et al. 2003). In contrast, Clark et al. (2008) report vigorous physical activity increases fracture risk regardless of bone mass (Clark, Ness & Tobias 2008). In addition, Ma (2004) found dynamic balance ability as the strongest factor in wrist and forearm fractures in children, while risk-taking behavior was associated most strongly with hand fractures (Ma 2004). The above findings give food for thought about the underlying reasons for falls in young people, especially boys.

3.5 Summary of fracture studies

Because children and adolescents fall frequently it has not been practical to obtain diary recall data to ascertain fall frequency in children with and without fractures. Nevertheless childhood and adolescent injuries are an important public health problem, and studies have shown that fracture rates have risen in the past decades, with a tendency from more severe to less severe injuries.

Fracture incidents seem to have a regional as well as seasonal tendency. Some areas and populations are more prone to fractures than others, boys tending to fracture more frequently than girls, and some children experience more fractures than others. Boys are known to be more physically active and more prone to take risks than girls during growing up, which can explain the higher incidence rate in fractures.

The increase in fractures during growth spurt in total has been explained by the transient physiologic osteoporosis (Parfitt 1994) but could also represent the combined result of the new types and higher risk physical activities children and adolescents undertake, together with the imbalance of the development of the bone properties and physical growth. On the one hand, lack of physical activity needed for adequate muscle strength may be deleterious to the ability to recover from a perturbation, on the other hand, very frequent sports participation and vigorous physical activity may induce a fracture. In addition, inactivity with overweight can be related to overloading of the bones at a fall. Not many studies correlating fracture risk and balance abilities in children have been published (Cheung, Detsky 2008). There seems also to be a void in research concerning fractures and postural stability in the otherwise healthy youth. The possibility of a transient lagging in coordination and postural control during growth spurts should be researched.

4 OVERWEIGHT AND OBESITY STUDIES

Obesity is a worldwide problem for all age groups. Overweight and obesity are steadily increasing in the developed countries with prevalence of obesity raised three-fold or more in many European countries since the 1980s (WHO. Regional Office for Europe. 2009). Also in Finland the prevalence of overweight and obesity has been increasing with age in women and men (Helakorpi et al. 2008, Kautiainen et al. 2002) as well as children and adolescents (Vuorela 2011). World Health Organization stated in 2005 that if the prevalence continues to increase at the same rate as in 1990s, it is estimated that about 150 million adults in the European region will be obese by 2010 (WHO/Europe 2005). According to WHO report 2008, prevalence of overweight and obesity in children and adolescents from 11- and 15- year-olds ranges from 5% to more than 30% in some countries (WHO. Regional Office for Europe 2009). Obesity and overweight are associated with serious diseases such as type 2 diabetes, cardiovascular and musculoskeletal diseases, certain cancers, and increased overall mortality (Haug et al. 2009). Consequences of childhood and adolescent obesity on children's motor performance, such as balance, locomotion and muscular strength, have not yet received much attention in the literature (Wearing et al. 2006, Allard et al. 2004, Robbins, Waked & Krouglicof 1998).

4.1 Body composition and anthropometry

Body composition measurements for evaluating overweight are used for a variety of clinical and research applications and can be estimated with both laboratory and field techniques. There are several methods and instruments that measure body composition, from high definition magnetic resonance and dual-energy x-ray densitometry to skinfold and circumference measurements. Calculating body composition by height to weight ratio is an additional method commonly used.

4.2 Body Mass Index

Body mass index (BMI) has been developed to measure accurately the relation between height and weight. It is the most common and easiest parameter used for assessing weight problems i.e. underweight, overweight and obesity on population level. BMI is calculated as weight (kg) divided by height squared (m^2). Children and adolescents have different age and gender specific cut-off-points from adults, but a theoretical optimum is set to BMI 21kg/m^2**.** The BMI range with the lowest mortality in adults is 18,5 to 25, with considerable variability between ethnic origin and age (Schopper 2005, Menschik et al. 2008). Leanness cut off point is 18.5, normal BMI should lie between 18.5 and 24.9, overweight cut point is 25, and obesity cut point is 30 (Cole 2000). Table 1 presents BMI classification according to World Health Organization (2006).Though BMI has some limitations such as failure to differentiate the proportional composition of the body i.e. the amount of fat mass versus lean mass it is commonly accepted in the public health field because it correlates sufficiently well with direct measures of total body fat and thus has the ability to ascertain differences in the normal population level (Hall 2006, Gómez-Ambrosi 2011).

Table 1. BMI classification for adults (WHO 2006).

BMI classification (kg/m^2)
< 18.5 lean/less than optimal weight
18.5 – 24.9 normal/ optimal weight
25.0 – 29.9 overweight
≥ 30.0 obese
30.0 – 34.9 obese class I
35.0 – 39.9 obese class II
≥ 40.0 obese class III

4.3 Anthropometry

Anthropometry is a set of methods of assessing the size, proportions and composition of the human body. World Health Organization states that anthropometric measurements are simple, universally applicable and non-invasive and they permit the evaluation and prediction of health, performance and survival of the person or population being measured (WHO 1995). McArdle et al. (1996) define the evaluation of body composition as the quantification of the different structural components of the body – muscle, bone and fat. The most common measurements assess body height and body weight and the relationship between weight and height (McArdle, Katch & Katch 1996).

4.4 Dual-Energy X-ray Absortiometry

In addition to the calculated body composition by BMI, fat mass, lean mass and fat percentage can be more accurately evaluated using a high technology imaging procedure called dual-energy X-ray absortiometry (DXA). DXA is used for quantification of fat mass, muscle mass and bone mineral content. It is a non-invasive method which is quickly becoming the "gold standard" replacing the more cumbersome hydrostatic weighing as it accurately presents an image of the tissues, permitting the quantification of the bone mineral content (BMC), total fat mass and fat-free body mass (Bonnick 2010).

4.5 Overweight, obesity and balance

The effects of weight on postural sway have been studied with somewhat differing results. Chiari et al. investigated the relationship between body sway oscillations and various anthropometric parameters. Their subjects were young adults who had body mass index ranging from 17.8 to 31.0 kg/m^2, which corresponds to an underweight/overweight range. Body weight correlated with mean speed of the center of pressure ($r = 0.43$) for conditions with vision (Chiari, Rocchi & Cappello 2002). Hue et al. (2006) reported that body weight accounted for most of the variance in balance stability in eyes open and closed conditions (52

% and 54 %, respectively), concluding that a decrease in balance stability is strongly correlated to an increase in body weight (Hue et al. 2007).

Contradicting this result, Forth et al. (2007) found in their study of healthy adult subjects that, BMI, height, weight or age did not make any significant contribution to changes in postural stability (Forth, Metter & Paloski 2007). Farenc and colleagues (2003) reported that thinner subjects had larger COG displacements than normal or corpulent subjects (Farenc, Rougier & Berger 2003). According to Menegoni et al. (2009) obesity affects both men and women in the AP displacement but only males in the ML direction (Menegoni 2009).

Several studies of overweight and obesity on postural stability in children and adolescents suggest that excess body weight causes postural instability by posing greater demands to the postural system to maintain and counteract perturbations to the equilibrium (Goulding et al. 2000, McGraw et al. 2000, Goulding et al. 2003, Wearing et al. 2006, Hue et al. 2007, Corbeil 2001).

According to Corbeil (2001) and Goulding et al. (2003) excess body weight hampers a person’s reaction time in perturbations (Goulding et al. 2003, Corbeil 2001). Greve et al. (2007) found in their study of males that high BMI demands more displacement to maintain postural balance (Greve et al. 2007). Menegoni reported that obesity affects male and female sway differently; men sway more in ML-direction than women but both genders sway more than normal weight subjects in AP-direction (Menegoni 2009).

In contrast, Blaszczyk et al. 2009 reported that overweight women portrayed a diminished static postural sway compared with normal subjects and that reduced postural sway range in voluntary dynamic sway tests substantially impedes dynamic stability especially in subjects with BMI over 40 (Błaszczyk et al. 2009).

Lee and Lin (2007) reported that the mesomorphic (muscular) children had significantly smaller mean radius of COP distribution than the endomorphic (round) or ectomorphic (lean) children in the eyes closed condition (Lee, Lin 2007). They explain the result by lower body height and higher muscular proportion. Allardt et al. (2007), reported that the ectomorphic group had the largest and statistically significant sway area covered by the time displacement of the COP, reflecting postural instability. They explained their results by low muscular component and a high height to weight ratio and relatively high center of mass (Allard et al. 2001).

Goulding et al. (2003) reported in their study of males from 10 to 21 years of age that the Bruiniks Oseretsky test revealed significantly lower scores for overweight boys than for the leaner subjects suggesting some aspects of functional balance are less efficient in heavier boys (Goulding et al. 2003). Similarly McGraw et al. (2000) found that obese boys had poorer balance than their lean counterparts (McGraw et al. 2000).

D’Hondt et al. (2008) found that in 8-10 year old boys there was a significant difference between the obese and the normal weight boys in sway velocity, walking speed and ability to hold balance on a beam, and that the step up/over test, the unilateral stance and the limits of stability were comparable with normal weight. They reported also that obese children had difficulties in fine motor skills especially in situations where postural stability is needed (D'Hondt et al. 2011). Similar findings by Bernard et al. (2003) suggest that obese adolescents have difficulty in fine tuning their balance on soft or uneven surfaces (Bernard et al. 2003).

4.6 Summary of overweight and obesity studies

Whether childhood obesity affects the function of the sensorimotor system has received comparatively little attention within the literature. Though some studies present that overweight hinders the sensory system in counteracting perturbations and poses more demands on postural systems, the focus has been mostly on its impact on skeletal structure and alignment, and to lesser extent its influence on motor performance, including strength, balance and locomotion (Wearing et al. 2006). Results whether overweight increases sway, have not been entirely consistent. Some studies are also highlighting the importance of studying children’s postural balance in relation to their body composition and the level of their physical activity in order to implement appropriate interventions for minimizing fracture risk (Goulding 2007).

5 PHYSICAL ACTIVITY

Physical activity is an important determinant of health. Insufficient physical activity is a risk factor for several chronic diseases (Haskell, Blair & Hill 2009). Regular exercise has been found to be beneficial for muscle strength (Stenevi-Lundgren et al. 2008), weight control (Menschik et al. 2008) and overall health, reducing the risk of many non-communicable chronic diseases in adulthood (Bauman, Craig 2005).

Karlsson (2007) stated that even though benefits of physical activity for young people's health in the long run are not yet well documented, there seems to be evidence that regular exercise is beneficial to skeletal health, aerobic fitness as well as postural stability (Karlsson 2007). Physical activity interventions have been reported to have a positive effect on bone mass (MacKelvie et al. 2003), structural changes in bone (Karlsson 2007, Nilsson et al. 2008) and muscle development in children (Stenevi-Lundgren et al. 2008).

As mentioned earlier in chapter 3, physical activity may increase fracture risk. Several studies have found that vigorous physical activity increases fracture risk also in children without deficits in bone mass which seems to indicate that there are other reasons for falling or losing balance, indicating that perhaps the frequency of activity raises the accident rate (Clark, Ness & Tobias 2008, Menschik et al. 2008, Ma, Jones 2002). Nevertheless the benefits of physical activity are estimated to cancel out the possible negative effects of being physically inactive (Karlsson 2007, Nilsson et al. 2008).

Children's and adolescents' physical activity levels are higher during childhood and decrease with age. In addition, physical activity patterns are often sporadic and do not thus reach recommended levels (Roberts, Tynjälä & Komkov 2004, Armstrong, Welsman 2006)). Nupponen (2010), on the other hand states in his study in Finland that there has been an upward trend in moderate to vigorous physical activity in children and adolescents during the years 2001 – 2005. His study also confirms that boys are more active than girls, and participated more in vigorous activities. In addition, intensity of physical activity was higher among the older than younger groups, whereas the younger participated more frequently in moderate to vigorous activities (Nupponen 2010).

5.1 Definitions of physical activity and exercise

Physical activity has been defined as any bodily movement produced by skeletal muscles that result in energy expenditure above resting level (Helakorpi et al. 2008).

There are different types of physical activity depending on the circumstance in which it takes place. Occupational physical activity takes place at work constituting sitting, standing and lifting activities, household physical activity, including garden and other domestic activities, leisure time physical activity, which means any type of activity with the purpose of increased energy expenditure such as exercise and sport. Leisure time physical activity can be divided into exercise, sport, household and other chores. This study focuses on leisure time physical activity.

Exercise is defined as a specific type of physical activity that is planned, structured and repetitive and aims to maintain physical fitness. Physical inactivity or sedentary behavior is a state in which body movement is minimal and energy expenditure approximates the resting metabolic rate (McArdle, Katch & Katch 1996).

Recommendation for an optimal physical activity level is at least 60 minutes of regular, moderate to vigorous intensity every day, varying the activities. Another recommendation for young who are very inactive is set to 30 minutes daily. As a rule of thumb, physical activity should result in sweating and elevated heart beat (HBSC 2001/2002).

Studies have shown that increasing the level of physical activity by only 15 minutes a day, being moderately active can have positive effects on weight and the overall health (Ness et al 2007). MacKelvie et al. (2003) found in their 2-year school study that a 10 minute, high impact circuit training/jumping intervention 3 times a week had substantial bone health effects (MacKelvie et al. 2003).

Menschik et al. (2008) have found in their study that the odds of becoming overweight as an adult is reduced by 5% for each day of PE-participation, and with participating in PE every 5 weekday decreased the odds by 28%. On the other hand they conclude that physical activity predicted normal-weight maintenance better than weight-loss, as the PE participation did not have the same positive salutary effect for overweight adolescents (Menschik et al. 2008).

5.2 Physical activity and balance

The controversy of physical activity and sports is that injury risk increases along with intensity and frequency. The effect of physical activity on postural stability has been broadly studied among the elderly population (Bellafiore 2010, Egerton, Brauer & Cresswell 2010, Fu 2009, Kaesler 2007), but the effect of physical activity on postural abilities in children and adolescents has not received much attention. The balance testing in children has focused mainly on functional balance rather than instrumental sway evaluation. This may be due to the fact that children's balancing abilities continue to develop until late adolescence making it even more difficult to standardize sway values for children. Welk et al. (2007) point out that children's physical and movement characteristics are unique and therefore require population specific measurement methods (Welk et al. 2007).

Whether physical activity has a positive influence on postural control seems to depend on the type of exercise and training (Calavalle et al. 2008, Gerbino, Griffin & Zurakowski 2007a, Golomer et al. 1999, Ericsson 2008). Several studies in the elderly population have confirmed the benefits of balance training in preventing falls (Bellafiore 2010, Fu 2009, Federici, Bellagamba & Rocchi 2005, Brooke-Wavell et al. 1998, Sihvonen 2005).

5.3 Physical activity assessment

Physical activity level is difficult to measure because most physical activity patterns change from day to day (Ridley et al. 2008). Individuals may be active one day and completely inactive at other periods of time making it difficult to quantify a person's physical activity level even with detailed information. There is also considerable variability between individuals in the energy expenditure of various activities and types of physical activity performed. In addition, there is the impact of physical fitness and health status, which can affect the levels and types of physical activity performed. These factors make it difficult to capture levels of physical activity to evaluate health-related interventions. (Welk 2002.)

Physical activity and exercise can be measured with very sophisticated, objective methods of doubly labeled water, indirect calorimetry, and respiratory gas analysis. In clinical use and epidemiologic studies these are impractical or too expensive. Devices such as heart rate monitors and movement sensor have become increasingly popular in measuring physical activity and can be used with larger groups of individuals.

Questionnaires are the most widely used method of measuring physical activity in epidemiological studies. Despite their long use, the physical activity questionnaires have received much criticism (Baranowski et al. 2008, Boon et al. 2008). Self-reported activity measures the subjective estimation of a person's physical activity (Armstrong 2006), and despite many validated questionnaires, in most cases the participants tend to overestimate their activity level and cannot recollect past activities correctly (Shephard, Vuillemin 2003). Nevertheless, questionnaires are traditionally used in studies with large populations because they are the most feasible and cost effective methods of estimating physical activity (Dollman et al. 2008, Rangul et al. 2008, Bauman et al. 2009).

Boon et al. (2008) compared the International Physical Activity Questionnaire Long Form (IPAQ-LF), the New Zealand Physical Activity Questionnaire Long Form (NZPAQ-LF) and Actigraph accelerometer with each other, and found that the questionnaires strongly correlated with each other (Spearman correlation coefficient, r = 0.79). They reported good agreement in the Bland-Altman method between both self-reported NZPAQ-LF and PIAQ-LF with ActiGraph accelerometer (CSA) in lower levels of activity, up to approximately 500 min x week^{-1} and 1000 min x week^{-1}, respectively, but when exercise increased, both questionnaires overestimated physical activity level. The IPAQ-LF and the NZIPAQ-LF produced a substantially higher (~165 %) physical activity mean score compared with the

ActiGraph accelerometer. In addition there were considerably lower validity correlations between ActiGraph and NZPAQ-LF data in the 51 to 65 year olds. Boon also noted that from the 64 subjects 33 (51 %) were young adults from 18 to 35 years of age which can have affected memory recall. (Boon et al. 2008.)

Rangul et al. (2008) investigated the WHO HBSC questionnaire and IPAQ-SF on adolescent physical activity. They present that the WHO HBSC represents substantial reliability (ICC 0.71 for frequency and ICC 0.73 for duration) girls having a higher ICC than boys in frequency estimation (ICC 0.87 for girls, ICC 0.59 for boys), but for IPAQ lower intra-class correlation coefficients were found (ICC between 0.10 and 0.62). Spearman correlation coefficients for validity for both the WHO HBSC and IPAQ-SF were measured against two objective instruments: cardiorespiratory fitness test (VO_{2peak}), and a seven days activity monitoring device ActiReg® which measures physical activity level (PAL) and total energy expenditure (TEE). Both questionnaires presented fair validity (r = 0.29 – 0.39) against $VO_{2peak,}$ but both questionnaires showed low correlation with PAL and TEE in adolescents (r = 0.01 and 0.29). They conclude that WHO HBSC questionnaire has substantial reliability and is an acceptable instrument for measuring cardiorespiratory fitness especially among girls (Rangul et al. 2008).

Craig et al. (2003) found the International Physical Activity Questionnaire (IPAQ) to have acceptable measurement properties, similar to other self-reports among 18 to 65 year old adults in diverse settings, and recommends the 7-day recall for national monitoring and the long form of the IPAQ for research purposes where more detailed information is required (Craig et al. 2003). Their international prevalence study in twelve countries across six continents demonstrated reasonable test-retest reliability (ICC range 0.7 – 0.80), concurrent validity between the forms (median rho = 0.67) and criterion validity around rho = 0.3 based on comparisons with IPAQ and accelerometer data (Craig et al. 2003).

6 MUSCLE STRENGTH

Butler and colleagues state that the leg muscles have two roles in human upright posture. They are the source of the sensory input that detects body sway and they produce the contractile force to correct body sway (Butler et al. 2008). Lower limb muscle strength has been found to be indicative of falls in the elderly population (Butler et al. 2008, Lord, Menz & Tiedemann March 2003). Coordination and lower limb strength exercises have been reported to decrease sway amplitudes and velocities (Park et al. 2008).

Surprisingly, Holm and Vollestad (2008) found that when compared with 8 to 12 years old boys, same age girls had better balance, even though they had weaker lower limb muscles and the ratio between hamstring and quadriceps strength was lower than in boys indicating that the hamstring muscles were weaker than quadriceps muscles (Holm, Vollestad 2008). A study by Handrigan et al. 2010 found that weight loss and muscular strength affect static balance control but that weight loss was more efficient in balance control than muscle strength (Handrigan et al. 2010). Couillandre et al. (2008) note that lower limb strength training responds to postural control, especially in populations with low initial level of physical activity.

Nevertheless, these kinds of studies in children are scarce. Many studies evaluate muscle performance and balance in children and adolescents with different deficits in one area or another (Hakkinen et al. 2006), but laboratory experimental studies in healthy children's muscle strength and balance abilities are difficult to find (Lin and Woollacott 2005).

7 PURPOSE OF THE STUDY

The purpose of this study was to investigate whether previous fracture history during growth, body composition, leisure time physical activity (LTPA) and inactivity level (PIA) is associated with body sway.

Study questions were

1) Have girls with large body sway suffered more upper limb fractures?

2) Do overweight and obese girls sway more than normal and underweight girls?

3) Do girls, whose lower limb extension force is lower, have a larger body sway than girls with higher lower limb force?

4) Do physically active girls have smaller body sway than physically inactive girls?

8 SUBJECTS AND METHODS

8.1 Study design

This cross-sectional study was part of the CALEX Family Study at the University of Jyväskylä. The CALEX Family Study is a longitudinal study with the aim of investigating the genetic and environmental factors that contribute to the variation in the development of body composition in girls transitioning from pre-puberty into early adulthood. Those girls who had completed balance tests at CALEX Phase III follow-up study in 2007 and 2008 were included in the current study.

8.2 Subjects

The study population consisted of 228 girls aged 17 to 21 years from Jyväskylä Municipality. Background information including lifestyle and behavioral characteristics as well as medical history was collected via a self-administrated questionnaire. The questionnaires were checked by a study nurse. Girls with no known serious health problems were included in the study. Written informed consent was obtained prior to the laboratory examinations. The measurements were carried out between 2007 and 2008 at the Department of Health Sciences of Jyväskylä University. All data were handled confidentially. The study protocol was approved by the ethical committee of the University of Jyväskylä and the Central Hospital of Central Finland.

From the 228 girls, 16 cases that had extreme values in their sway variables were excluded from the analyses. The remaining 212 cases were analyzed in the study.

8.3 Methods

8.3.1 Balance measurements

Postural sway was measured with a computer based force platform system (Good Balance ™, Metitur Ltd, Finland). The system consists of an equilateral triangular platform (width 800mm, height 70mm) fitted inside a frame with hand rails encircling the platform for protection, an electronic unit (an amplifier, an analogue/digital-converter, and a computer). The software is based on Microsoft Windows operating system. The computer and the analogue/digital-converter communicate via a standard serial port. Sampling frequency was 50 Hz, the analogue signals were converted to digits by a 12-digit, 8-channel A/D converter (Good Balance user's manual 2004, 4-5).

On the basis of the vertical force signals from each corner of the platform, the system calculates the x (medio-lateral, ML) and y (antero-posterior, AP) coordinates of the center of pressure (COP) affecting the platform when the test person is standing on it. On the basis of values at these coordinates, the mean velocity of ML and AP sway (mm/s) as well as the velocity moment (VM) (mm^2/s) was calculated. In the calculation of the velocity moment, both the velocity of the moment of the COP and its actual distance from the center of the test are taken into account and the result is expressed as the mean area covered by the movement of the COP during each second of the test. The velocity moment can be considered as an overall indicator of performance. The program was set to automatically adjust for the height and location of body mass. In the analysis we used the values scaled for height for ML and AP (Reference data using Finnish population) (sway variable/person's height (cm) x 180cm. (Good Balance user's manual, 15.)

Test setting for balance measurement

The test setting was a peaceful room at the Laboratory of Sport and Health Sciences, Jyväskylä University. The subjects were informed about the test procedure prior to the test. The subjects were tested at different times of day because of their personal daily schedules.

After the test a short oral feedback about the balance results was given to the subjects. All tests were performed twice and in the same order.

Test procedure

The speed of the antero-posterior (AP) and medio-lateral (ML) sway and the velocity moment (VM) was calculated from the following trials: 1) bi-pedal stance with eyes open (OE), 2) bi-pedal stance with eyes closed (CE), 3) semi-tandem stance with left foot in front (STL), and 4) semi-tandem stance with right foot in front (STR). Each measurement started with a 3 s delay before the actual calculation of the balance trial, to give the testee time to take the required posture and concentrate on the measurement. All subjects attended a single testing session with two trials for each stance condition. The subjects were asked to stand as still as possible, without shoes, with their hands held together in front of the hips, focusing their gaze at a mark about 2 meters in front of them at eye level. Total testing time lasted about 15 min. There was a 30 s rest period between the first and the second trial, and a 60s resting period between different tests. The calibration of the platform was done once a week. In addition, the force platform automatically performed a self-calibration test every time the computer program was opened.

In the eyes open and closed bi-pedal stance, the position of the feet was not predetermined, the subjects stood for 30 s in a comfortable stance, not broader than their shoulder width. In the semi tandem eyes open subjects stood for 20 s with the first metatarsal of the foot behind touching the middle of the calcaneus bone of the foot in front. Small values in sway velocity and amplitude are considered to represent good postural control (Era et al. 2006), hence, the smallest sway values in each condition were chosen for the analysis.

8.3.2 Anthropometric measurements

All anthropometric measurements were performed after an overnight fasting (12 h). Participants were weighed in light clothes and without shoes. Weight was determined within 0.1 kg for each subject using an electronic scale, calibrated before each measurement session. Height was determined using a fixed wall-scale measuring device to the nearest 0.1 cm. Body mass index (BMI) was calculated as weight (kg) per height (m^2). The subjects were then divided into three groups according to their BMI scores: Lean (BMI < 18.49), Normal weight (BMI 18.5 – 24.49) and Overweight / Obese (BMI > 24.5 – 29.99 and BMI > 30, respectively). Overweight and obese subjects were allocated to one group because there were only four obese subjects in the data.

8.3.3 Body composition assessment

Dual-energy X-ray absorptiometry (Prodigy, GE Lunar Corp., Madison, WI USA with software version 9.3) was used to estimate fat mass (FM), and lean mass (LM) of the total body. All metal items were removed from the participants to ensure the accuracy of the measurement. The subjects were positioned in the center of the table for each scan. They were scanned using the default scan mode automatically selected by the Prodigy software.

8.3.4 Muscle performance

Knee extensor strength

Maximum isometric strength of the left knee extensors (Max KE) were measured with a dynamometer of isometric muscle strength measurements (Metitur, Finland™). The subjects performed three trials from which the best result was used for the analysis.

Jumping height

Lower limb explosive performance capacity (Jump) (cm) was evaluated using a vertical counter movement jump test. The test was performed on a contact platform recording the height of the jump in centimeters.

8.3.5. Physical activity assessment

Leisure time physical activity (LTPA) level was evaluated using a self-administrated physical activity questionnaire which was a modified version of a validated questionnaire used in a previous WHO study (Hickman et al 2000, Prochaska et al 2001). The modification consisted of two additional questions asking about the frequency and duration of physical exercise. Specifically, the questionnaire asked the girls what were the first, second, and third most common sports they participated in, the duration of exercise in each session, and the number of sessions each week. The intensity of each activity was calculated on the basis of the energy expenditure per minute (McArdle et al 1996). Bone loading was based on whether the activity was weight bearing or not. We constructed a formula to calculate the LTPA score:

LTPA Score = frequency $\times \sum_{1-3}(\text{intensity index} \times \text{duration} \times \text{loading})$,

where frequency = times per week, 1-3 = the three physical activities, intensity index = MET value according to body mass, duration = hours per session, loading: non-weight bearing = 1 and weight bearing = 2. The subjects were then divided into three LTPA groups according to the level of their activity.

Physical inactivity (PIA) was calculated as the sum of sitting and lying hours per day.

8.3.6 Fracture data collection

Fracture history data was collected from health centers and central hospitals. Only fractures that were verified by a doctor and an x-ray were accepted in the study analysis. In addition, fractures that had been sustained during labor or the first year of life were excluded as they were considered not to be related to postural stability. Fractures that had occurred between the ages 2 and 18 years were included in the study. The subjects were allocated into two groups i.e. no-fracture (NF) and fracture (F). The fracture mechanism varied from modest tumbling on an even plane, to falls from > 0.5m and to moving falls on downhill surfaces i.e. on snowboards, skis, sledges or bicycles. Fracture sites considered were both upper and lower extremity fractures.

8.4 Statistical analyses

Descriptive statistics (means and standard deviations) were calculated for all the measured and calculated variables in samples. Non-parametric techniques were used when a parametric analysis was not applicable.

Distribution of the data was checked by Shapiro-Wilk's W test, and to test homogeneity Levene's test of homogeneity has been used.

Differences in anthropometric, balance and physical fitness variables between the two fracture groups were analyzed by independent t-test or Mann-Whitney U test. Differences among the three LTPA groups and differences among the three BMI groups were analyzed by one-way ANOVA or Kruskal-Wallis ANOVA.

A Chi-square test for independence was used to determine whether the Fracture and BMI- or Fracture and LTPA groups were related.

A multiple regression analysis was used to assess the ability of anthropometric characteristics (body height, body weight, BMI, FM, F%, LM), jumping height, max KE force, and LTPA, PIA to predict sway speed or velocity moment. In addition, F and NF groups were re-coded as dummy variables for regression analysis. In the method, independent variables are entered into the equation in the order specified by the researcher based on theoretical grounds by past research and expectations (Field 2009, 213). Thus body height and body weight were entered in the first block. Probability of F was set to $\leq .05$. A log-transformation of the non-normally distributed variables was used to fit the assumptions of the regression analysis.

All the data were analyzed by SPSS version 16, at 5% level of random error.

9 RESULTS

9.1 Physical characteristics of the subjects

The characteristics of the sample are presented in Table 2. The subjects' mean age was 18.6 years (SD ±1.1), they were 166 cm tall (SD ±5.6) and weighed 60.3 kg on average (SD ±10.4). The participants provided a sample with a wide range in BMI from 15.6 to 37.3, in FM from 7.5 to 53.1 kg and in LM from 28.8 to 53.6 kg. Figure 1 shows that 75 % (n = 157) of the girls had normal body mass index, 10 % were in the lean group (n = 23). In the overweight group there were 13 % overweight (n = 28) and 2 % obese (n = 4) girls. Girls showed a wide range in LTPA scores as well, between 0.4 and 899, and their PIA hours varied between 8 and 24. They had 384 N (SD ±94.3) isometric strength in their knee extensors (Max KE) on average, and the mean of their jumping height was 22 cm (SD ± 5.0).

Table 2. Basic characteristics of the subjects.

	N	Mean	95%CI	Minimum	Maximum
Age (years)	212	18.6	(18.4 - 18.7)	17.0	21.0
Height (cm)	212	166	(165 - 166)	149	181
Weight (kg)	212	60.3	(58.9 - 61.7)	40.0	103.0
BMI (kg × m-2)	212	21.9	(21.5 - 22.4)	15.6	37.3
FM (%)	207	30.8	(29.8 - 31.8)	15.9	51.3
FM (kg)	207	19.2	(18.1 - 20.2)	7.5	53.1
LM (kg)	207	38.2	(37.6 - 38.8)	28.8	53.6
Jump height (cm)	206	22.0	(21.3 - 22.7)	10.7	39.3
Max KE (N)	202	384	(371 - 397)	147	692
LTPA	183	168	(144 - 193)	0.4	899
PIA (hours)	194	17.7	(17.3 - 18.1)	8.0	24.0

FM%= fat mass percentage derived from DXA, FM=fat mass derived from DXA, LM=lean mass derived from DXA, KE= Knee extension, LTPA=leisure-time physical activity, PIA=physical inactivity.

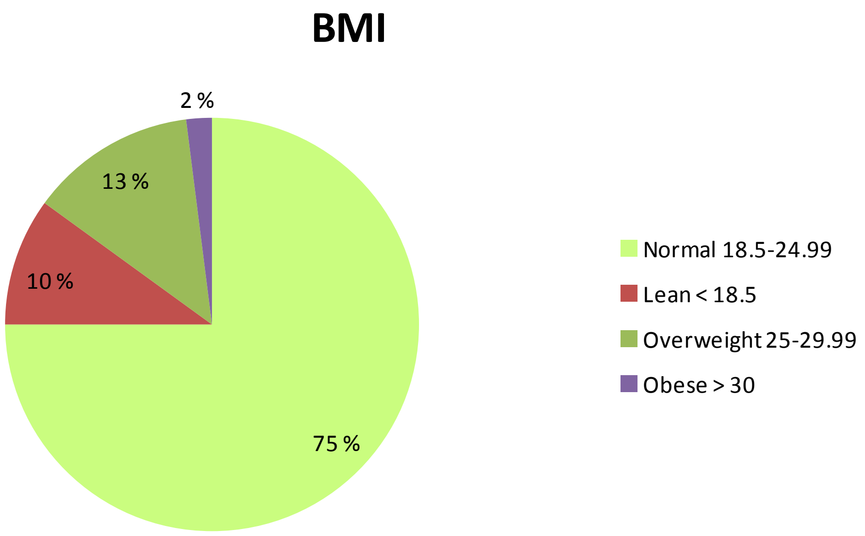

Figure 1. Distribution of the girls among the BMI categories. (Overweight and Obese groups are presented separately in the figure to emphasize their distribution, but they are considered as one group in the analysis.)

9.2 Differences between fracture and non-fracture groups

From the total of 212 subjects, 75.9 % (n = 161) had never had a fracture and 24.1 % (n = 51) of the subjects had sustained fractures between two and eighteen years of age.

Table 3 shows that there were no differences in age, body height, body weight, BMI, FM%, FM, and LM between the two fracture groups. Furthermore, no differences were found in jumping height and Max KE. In the LTPA scores between the fracture groups there was a non significant trend indicating that girls without fractures were slightly more active than the fracture group girls (p = 0.163). Of the NF group, 31.9 % belonged to the Low, 31.2 % to the Medium, and 37 % belonged to the High LTPA group. The F group was physically slightly less active as 40 % of the fractured girls belonged to Low LTPA group, compared with 31.9 % in the NF group, and on the other hand, 24.4 % of fractured girls belonged to the High LTPA group, compared with 37 % in the non fracture. There was a significant difference in physical inactivity hours between the two fracture groups (p=.003). Girls in the fracture group spent about one hour more time sitting and lying down than the non-fractured girls. The F group had significantly smaller (better) values of VM-EO (p=0.047) and AP-CE (p=0.042) than the NF group, but there were no significant differences in the other balance variables between the fracture groups. A Chi-square test for independence indicated no significant association between fracture and BMI (χ2 = 2.43, p = .297).

Table 3. Results of the independent t-test and Mann-Whitney U test between the groups.

	No fracture (n=161)		Fracture (n=51)		t-test
	Mean	95%CI	Mean	95%CI	p
Age (years)	18.6	(18.5 - 18.8)	18.4	(18.1 – 18.7)	0.183
Height (cm)	166	(165 – 166)	165	(163 – 166)	0.488
Weight (kg)	60.4	(58.7 – 62.1)	59.8	(57.2 – 62.3)	0.956
BMI (kg x m-2)	21.9	(21.4 – 22.5)	21.9	(21.1 – 22.6)	0.423
FM%	30.6	(29.5 – 31.8)	31.4	(29.6 – 33.2)	0.281
FM (kg)	19.1	(17.9 – 20.4)	19.2	(17.4 – 21.0)	0.454
LM (kg)	38.3	(37.6 – 39.0)	37.8	(37.0 – 39.0)	0.668
Jump height (cm)	22.1	(21.3 – 22.9)	21.6	(20.3 – 22.8)	0.486
Max KE (N)	381	(366 – 397)	393	(369 – 418)	0.484
LTPA score	177	(148 – 206)	142	(98 – 185)	0.163
PIA (hours)	17.4	(16.9 – 17.9)	18.7	(18.0 – 19.4)	0.003
ML-OE (mm×s-1)	2.9	(2.7 – 3.0)	2.8	(2.6 – 3.1)	0.744
AP-OE (mm×s-1)	4.1	(4.0 – 4.3)	4.1	(3.8 -4.4)	0.899
VM-OE (mm2×s-1)	4.6	(4.3 – 5.0)	4.0	(3.4 – 4.6)	0.047
ML-CE (mm×s-1)	3.6	(3.5 – 3.8)	3.6	(3.2 – 3.9)	0.561
AP-CE (mm×s-1	6.5	(6.2 – 6.8)	6.1	(5.4 – 6.8)	0.042
VM-CE (mm2×s-1)	8.1	(7.5 – 8.8)	8.3	(7.0 – 9.7)	0.947
ML-STL (mm×s-1)	7.8	(7.5 – 8.2)	7.2	(6.5 – 7.9)	0.179
AP-STL (mm×s-1	7.2	(6.8 – 7.5)	7.2	(6.6 – 7.8)	0.928
VM-STL (mm2×s-1)	19.5	(18.2 – 20.7)	18.5	(16.0 – 21.1)	0.251
ML-STR (mm×s-1)	7.3	(6.9 – 7.7)	6.9	(6.2 – 6.8)	0.410
AP-STR (mm×s-1)	7.1	(6.8 – 7.5)	6.8	(6.2 – 7.4)	0.420
VM-STR (mm2×s-1)	18.3	(17.1 – 19.4)	17.3	(15.4 – 19.2)	0.679

FM%= fat mass percentage derived from DXA, FM=fat mass derived from DXA, LM=lean mass derived from DXA, KE= Knee extension, LTPA=leisure-time physical activity, PIA=physical inactivity, ML= medio-lateral, AP= antero-posterior, OE=eyes open, CE=eyes closed, STL=semi-tandem left, STR=semi-tandem right.

9.3 Differences among LTPA groups

Table 4 shows that there was a significant difference in body height, FM%, LM and jumping height, across LTPA groups ($p < 0.05$, respectively). The girls in the High LTPA were significantly taller, had smaller FM%, had more LM, and could jump higher than that of girls in the Low LTPA ($p < 0.05$, respectively). Girls in the High LTPA also had more LM than girls in the Medium LTPA ($p = 0.016$). All the LTPA groups differed from each other in LTPA scores ($p < 0.001$, respectively).

There were no significant differences in balance variables between the LTPA groups. There were no differences in age, body weight, BMI, FM, maximal isometric knee extension force, and physical inactivity hours PIA between the LTPA groups (Table 4).

Table 4. Results of the ANOVA and Post-Hoc tests among three LTPA groups.

LTPA Groups	Low	(n = 62)	Medium	(n = 59)	High	(n= 62)	Post-Hoc Tests		
	Mean	(95% CI)	Mean	(95% CI)	Mean	(95% CI)	L-M	L-H	M-H
Age (yrs)	18.5	(18.2 - 18.8)	18.8	(18.5 - 19.1)	18.5	(18.3 - 18.8)	0.253	0.996	0.290
Height (cm)	164	(163 - 166)	165	(164 - 167)	167	(165 - 169)	0.610	0.028	0.268
Weight (kg)	58.6	(56.1 – 61.0)	59.5	(57.3 - 61.6)	60.9	(58.4 - 63.4)	0.762	0.316	0.745
BMI (kg x m-2)	21.6	(20.8 - 22.4)	21.7	(21 - 22.5)	21.9	(21.1 - 22.5)	0.971	0.951	0.995
FM%	32.4	(30.7 - 34.1)	30.7	(28.9 - 32.5)	28.7	(26.9 - 30.4)	0.716	0.007	0.207
FM (kg)	19.5	(17.7 - 21.3)	18.7	(17 - 20.4)	18.0	(16.2 - 19.7)	0.880	0.176	0.404
LM (kg)	36.1	(35.1 - 37.1)	37.9	(37 - 38.7)	39.9	(38.9 - 40.9)	0.138	0.000	0.016
Jump height (cm)	20.7	(19.6 - 21.8)	22.8	(20.8 - 23.5)	23.8	(22.5 - 25.1)	0.369	0.001	0.115
Max KE (N)	372	(346 - 398)	376	(353 - 399)	396	(372 - 421)	0.971	0.341	0.469
LTPA score	29.4	(24.2 - 34.6)	122	(113 - 130)	352	(311 – 393)	<0.001	<0.001	<0.001
PIA (hours)	18.3	(17.6 - 19.1)	17.6	(16.8 - 18.3)	17.5	(16.8 - 18.1)	0.399	0.282	0.975
ML-EO (mm x s-1)	2.9	(2.7 – 3.1)	2.8	(2.6 – 3.0)	2.8	(2.6 – 3.1)	0.936	0.952	0.999
AP-EO (mm x s-1)	4.0	(3.7 – 4.2)	4.1	(3.9 – 4.4)	4.1	(3.9 – 4.3)	0.674	0.595	0.993
VM-EO (mm^{2}xs-1)	4.4	(3.9 – 5.0)	4.6	(4.1 – 5.1)	4.5	(3.9 – 5.1)	0.872	0.998	0.901
ML-EC (mm x s-1)	3.7	(3.4 – 4.0)	3.5	(3.3 – 3.8)	3.5	(3.2 – 3.8)	0.771	0.893	0.969
AP-EC (mm x s-1)	6.0	(5.5 – 6.4)	6.4	(5.9 – 6.9)	6.6	(6.1 – 7.1)	0.662	0.640	1.000
VM-CE (mm^{2}xs-1)	8.0	(6.9 – 9.2)	7.6	(6.7 – 8.6)	8.4	(7.2 – 9.6)	0.950	0.925	0.777
ML-STL (mm x s-1)	7.1	(6.5 – 7.8)	7.8	(7.3 – 8.4)	8.0	(7.6 – 8.8)	0.170	0.067	0.912
AP-STL (mm x s-1)	7.1	(6.5 – 7.6)	7.1	(6.5 – 7.6)	7.3	(6.7 – 7.9)	1.000	0.909	0.913
VM-STL (mm^{2}xs-1)	18.8	(16.5 – 21.0)	19.0	(17.0 – 21.0)	19.9	(17.7 – 21.9)	0.953	0.593	0.782
ML-STR (mm x s-1)	7.1	(6.5 – 7.7)	7.0	(6.4 – 7.6)	7.4	(6.8 – 8.0)	0.996	0.651	0.710
AP-STR(mm x s-1)	6.9	(6.3 – 7.5)	7.1	6.6 – 7.6)	7.1	(6.6 – 7.6)	0.655	0.638	1.000
VM-STR (mm^{2}xs-1)	18.3	(16.6 – 20.0)	17.0	(15.0 – 19.1)	18.0	(16.5 – 19.8)	0.360	0.946	0.215

FM%= fat mass percentage derived from DXA, FM=fat mass derived from DXA, LM=lean mass derived from DXA, KE= Knee extension, LTPA=leisure-time physical activity, PIA=physical inactivity, ML=medio-lateral, AP=antero-posterior, EO=eyes open, EC=eyes closed, STL=semi-tandem left, STR=semi-tandem right, L-M=Low-Medium, L-H=Low-High, M-H=Medium-High.

9.4 Differences among BMI groups

There was a significant difference in body weight, BMI, FM%, FM, LM, jumping height ($p < .01$). The girls in OW/Obesity group had significantly better results in Max KE than girls in the Lean group ($p =0.015$). No significant differences were found in age, body height, LTPA scores, PIA, and in any of the sway variables among the BMI groups (Table 5).

Table 5. Results from the ANOVA and Post-Hoc tests among BMI groups.

BMI Groups	Lean (n = 23)		Normal (n=157)		OW & Obese (n=32)		Post-Hoc Tests		
	Mean	(95% CI)	Mean	(95% CI)	Mean	(95% CI)	L-N	L-O	N-O
Age (yrs)	18.7	(18.2- 19.2)	18.6	(18.4 - 18.7)	18.6	(18.3 – 19.0)	0.828	0.969	0.939
Height (cm)	165	(162 - 168)	166	(165 - 166)	166	(164 - 168)	0.924	0.748	0.796
Weight (kg)	48.5	(46.4 - 50.5)	58.6	(57.6 - 59.7)	76.8	(73.4 - 80.3)	<0.001	<0.001	<0.001
BMI (kg x m-2)	17.7	(17.4 – 18.1)	21.3	(21.1 - 21.6)	27.7	(26.7 - 28.7)	<0.001	<0.001	<0.001
FM%	22.9	(21.2 – 24.6)	29.8	(28.9 - 30.7)	41.8	(40.2 - 43.3)	<0.001	<0.001	<0.001
FM (kg)	11.1	(10.1 – 12.1)	17.7	(17 - 18.4)	32.4	(29.9 - 34.9)	<0.001	<0.001	<0.001
LM (kg)	35.2	(33.6 - 36.8)	38.1	(37.4 - 38.7)	41.0	(39.4 - 42.7)	0.007	<0.001	0.006
Jump height (cm)	23.7	(21 – 26.4)	22.4	(21.7 - 23.2)	18.5	(17.3 - 19.7)	0.617	<0.001	<0.001
Max KE (N)	343	(311 - 375)	381	(366 - 395)	427	(389 - 466)	0.204	0.015	0.178
LTPA score	136	(73 – 199)	173	(145 - 201)	169	(88 - 249)	0.052	0.264	0.906
PIA (hours)	16.4	(15.1 – 17.7)	17.9	(17.5 - 18.4)	17.7	(16.4 – 19.0)	0.032	0.223	0.876
ML-EO (mm x s-1)	2.9	(2.6 – 3.2)	2.9	(2.8 - 3.0)	2.7	(2.3 - 3.0)	0.843	0.200	0.178
AP-EO (mm x s-1)	3.9	(3.6 – 4.2)	4.1	(4.0 - 4.3)	4.3	(3.9 - 4.7)	0.805	0.564	0.754
VM-EO (mm^{2}xs-1)	4.4	(3.5 -5.2)	4.5	(4.1 - 4.8)	4.7	(3.7 - 5.7)	0.981	1.000	0.971
ML-EC (mm x s-1)	3.8	(3.2 – 4.4)	3.6	(3.5 - 3.8)	3.3	(3.0 - 3.7)	0.389	0.109	0.375
AP-EC (mm x s-1)	5.6	(4.8 – 6.4)	6.5	(6.2 - 6.8)	6.6	(5.7 - 7.4)	0.141	0.322	0.986
VM-CE (mm^{2}xs-1)	7.9	(5.6 - 10.1	8.3	(7.6 – 9.0)	8.1	(6.7 - 9.4)	0.798	0.798	0.985
ML-STL (mm x s-1)	6.8	(5.5 – 8.1)	7.7	(7.4 - 8.1)	8.1	(7.4 - 8.9)	0.186	0.102	0.660
AP-STL (mm x s-1)	7.5	(6.5 – 8.4)	7.1	(6.7 - 7.4)	7.5	(6.7 - 8.4)	0.675	1.000	0.577
VM-STL (mm^{2}xs-1)	20.8	(17.4 – 24.2)	18.0	(17.6 - 20.1)	19.9	(16.7 - 23.1)	0.528	0.866	0.858
ML-STR (mm x s-1)	6.8	(5.6 – 8.1)	7.3	(7.0 - 7.7)	7.0	(6.0 - 7.9)	0.644	0.998	0.611
AP-STR(mm x s-1)	6.5	(5.5 - 7.5)	7.1	(6.7 - 7.4)	7.4	(6.5 - 8.2)	0.546	0.503	0.928
VM-STR (mm^{2}xs-1	18.2	(15.1 – 21.2)	17.7	(16.5 - 18.9)	19.6	(17.1 - 22.2)	0.860	0.898	0.440

FM%= fat mass percentage derived from DXA, FM=fat mass derived from DXA, LM=lean mass derived from DXA, KE= Knee extension, LTPA=leisure-time physical activity, PIA=physical inactivity, ML=medio-lateral, AP=antero-posterior, EO=eyes open, EC=eyes closed, STL=semi-tandem left, STR=semi-tandem right, OW=Overweight, L-N=Lean-Normal, L-O=Lean-Overweight & Obese, N-O=Normal-Overweight & Obese.

9.5. Regression analysis results

Summary of the regression analysis for variables predicting medio-lateral sway with open and closed eyes, velocity-moment of open and closed eyes stances are presented in Table 5.

ML-OE: Height and weight were entered at Step 1, explaining 3 % of the variance in medio-lateral sway with open eyes. After entry of the Max KE at Step 2, the total variance explained by the model was 7.3 % ($p = 0.002$). Max KE explained an additional 4.3 % in ML-OE after controlling for height and weight ($p = 0.003$).

VM OE: Height and weight were entered at Step 1, explaining 1.8 % of the variance in the velocity moment with open eyes. After entry of the Max KE at Step 2, the total variance explained by the model as a whole was 5.6 % ($p = 0.010$). The Max KE explained an additional 3.8 % of the variance in VM-OE after controlling for height and weight ($p = 0.006$).

ML-CE: Height and weight were entered at Step 1, explaining 5.1% of the variance in medio-lateral sway with closed eyes. After entry of the Max KE at Step 2, the total variance explained by the model as a whole was 7.1 % ($p = 0.002$). Max KE explained an additional 2.0 % of the variance in ML-CE after controlling for Height and Weight ($p = 0.04$).

VM-CE: Height and weight were entered at Step 1, explaining 3.0 % of the variance in the velocity moment with closed eyes. After entry of the Max KE at Step 2, the total variance explained by the model as a whole was 4.6 % ($p = 0.024$).

Table 6. Summary of the regression results.

	B	SE	β	p
ML-OE				
Step 1				
Constant	4.63	1.85		
Height	0.01	0.01	0.10	.231
Weight	-2.34	0.95	-0.20	.014
Step 2				
Constant	2.92	4.52		
Height	0.01	0.05	0.04	.214
Weight	-1.42	0.98	-0.12	.147
Max KE	-0.00	0.00	-0.22	.003
R2 = .03 for step 1, Δ R2 = .04 (p < .05)				
VM-OE				
Step 1				
Constant	-4.12	4.98		
Height	0.56	0.32	0.14	.086
Weight	-0.34	2.55	-0.01	.894
Step 2				
Constant	-6.44	4.97		
Height	0.06	0.03	0.14	.078
Weight	1.95	2.64	0.06	.461
Max KE	-0.01	0.00	-0.21	.006
R2 = .02 for step 1, Δ R2 = .04 (p < .05)				
ML- CE				
Step 1				
Constant	3.58	2.94		
Height	0.04	0.02	0.21	.011
Weight	-3.87	1.28	-0.24	.003
Step 2				
Constant	2.71	2.51		
Height	0.04	0.02	0.21	.010
Weight	-3.02	1.33	-0.19	.025
Max KE	-0.00	0.00	-0.15	.040
R2 = .05 for step 1, Δ R2 = .02 (p < .05)				
VM- CE				
Step 1				
Constant	-7.70	10.20		
Height	0.16	0.07	0.20	.014
Weight	-6.31	5.23	-0.10	.229
Step 2				
Constant	-10.89	10.28		
Height	0.16	0.07	0.20	.013
Weight	-3.16	5.47	-0.05	.564
Max KE	-0.01	0.00	-0.14	.064
R2 = .03 for step 1, Δ R2 = .02 (p > .05)				

10 DISCUSSION

The purpose of this study was to assess the relationship between body composition and sway characteristics, and whether lower limb strength, physical activity or inactivity have an association with body sway in healthy girls. In addition we studied if the girls, who had suffered fractures during growing up, would have a larger sway compared to the ones who had not sustained fractures, and whether the two groups would differ in their physical activity levels as well as their anthropometric measures.

10.1 Main findings

Body sway in fracture and none-fracture groups

In the current study previous history of fractures was not associated with body sway velocity or velocity moment. In addition, neither fracture nor lack of fracture could predict sway pattern. The only other study we found in previous history of fractures and body sway adolescents was presented by Goulding et al (2003). Similarly to our results, they did not find any association with previous history of distal forearm fractures and abnormal postural sway (Goulding et al 2003). Similar assessment methods for postural sway as in the current study have been successfully used in the older population (Sihvonen 2004, Era et al 2006). In younger persons though, when assessing possible deficits in balance abilities or risk factors for falls, the methodology and test settings should be revised in order to detect the possible causes for childhood falls with fractures.

LTPA in fracture and none-fracture groups

Studies have confirmed that there is a direct relationship between high activity levels with certain type of activity and the incidence of accidents (Clark, Ness & Tobias 2008, Jones et al. 2001). In contrast, our study did not support these findings, as the subjects in the NF group spent more time in leisure time sports than the F group. The difference was not significant (p = 0.163) but it could perhaps be described as a trend. Reason for this could be that the majority of these subjects did not partake in high risk-, high intensity sports activities, which is in accordance with the results from Ma et al (2003) that light physical activity is protective of fractures (Ma 2003). Interestingly, another study within the Calex Family Study in girls found that the fractured girls had lower bone mass and were taller than the girls who had not sustained a fracture during growing up (Cheng et al. 2009).

Anthropometric, body composition, lower limb strength association with sway indices

In our study maximal isometric lower limb force (Max KE) was an important variable in predicting sway, but only in certain sway indices. Max KE was found to have an inverse association with sway, presenting weaker maximal knee extension strength with increased sway speed in medio-lateral direction in the eyes open and closed conditions (ML-OE and ML-CE), and velocity moment in open eyes conditions (VM-OE), and was nearly significant in velocity moment in closed eyes (VM-CE) condition. This result is in accordance with other studies in adults and elderly (Couillandre et al. 2008, Yaggie, Campbell 2006, Wu et al. 2002, Liu-Ambrose et al. 2003), and may indicate the importance of the strength of the leg musculature in controlling sway. There was, nevertheless, no significant difference in Max KE between the two fracture groups.

In our study body height contributed significantly to ML-CE and VM-CE. The individual contribution of this independent variable was very low but relatively consistent: body height explained between 2.5 % and 4.5 % of the body sway. It has to be taken into account also that height was automatically adjusted for by the Good Balance™ computer program thus accounting for the effect of height on body sway. Even with such low levels of significance, the results are in accordance with other studies (Era et al. 2006, Handrigan et al.2010), suggesting that a relationship exists between body height and body sway.

Body weight made a weak contribution only in ML-CE. In our sample the percentage of overweight subjects was (13 %), and obese subjects (2 %), which is in agreement with the Finnish survey data in 18 years old girls (overweight prevalence was 12.5 % and obesity prevalence was 3.5 %) (Kautiainen et al. 2002). The finding by Blaszczyk et al. (2009) that weight has an inverse relationship with sway is confirmed only in ML-CE condition in our study (Blaszczyk et al. 2009), and will require more studies with overweight subjects to be consistently confirmed.

Differences between body sway in LTPA and PIA groups

Interestingly, the more inactive girls had a smaller body sway than the physically active group, which did not support our assumption. Similarly, Paksuniemi and Saira’s (2004) results show smaller sway velocities for the non-athletic group compared with the recreational athletes or the competitive athletes (Paksuniemi 2004). A study in expert gymnasts and non-gymnasts reported that closing the eyes affected the expert gymnasts similarly to the non-gymnasts, independent of the difficulty of the posture (Asseman, Caron & Cremieux 2008). In our study, correspondingly, there were no significant differences between the LTPA groups in any body sway condition meaning that all three physical activity groups reacted similarly to different stance conditions.

Differences between body sway indices

The girls swayed more in antero-posterior direction than in the medio-lateral direction in normal bipedal stance condition with eyes open, which is in accordance with other studies (Era et al. 2006). Removing vision resulted in larger sway in both directions, again antero-posterior sway presented larger sway than medio-lateral sway. Diminishing the stance support area had an even stronger effect on sway pattern in both directions, medio-lateral sway presenting a larger sway than antero-posterior body sway.

As the study population consisted of healthy, young females, the results may be considered to represent the sway variance of healthy young women in normal population but not for some special physical condition groups, such as children with muscle dystrophy or neural disorder. Nevertheless, early detection of postural deficits, appropriate interventions and balance training may prevent not only individual tragedies but lessen the societal economic burden of health care.

10.2 Limitations to the study

Some limitations to the study are worth mentioning. Balance was tested depending on the subjects own personal schedules, sometimes early in the morning, sometimes very late in the evening. This may have affected the results as daytime changes in postural stability, attention, arousal, nutrition and hemodynamics may influence sway (Conforto et al. 2001, Maki, McIlroy 1996, Forsman et al. 2007).

Posturography sway measurements evaluate the different sensory strategies that a human body uses to control balance and thus lack the functional information that for instance clinical balance tests measure. Using both posturography tests and functional balance tests together when assessing balance abilities may be better to differentiate a person's postural steadiness.

The subjects in the current study were healthy young females whose postural stability according to literature is at its best (Era et al. 2006). For presumably healthy, young populations like these, a ceiling effect may be present, and thus possible, subtle deficiencies in postural stability may be unnoticed. For these populations, a single leg stance protocol may be more suitable. Different assessment tools such as kinematic and bioelectrical assessment could be combined as well. The choice of methodology in analyses should be carefully chosen, in order to reach a broader understanding of the factors influencing sway in different age groups (Horak 2006, Visser et al. 2008, Davis 2010, Doyle et al. 2008).

Fracture data was achieved from the hospital records and the reason for the fracture was retrieved from a questionnaire. Questionnaires rely on the subject's memory recall which has been known to be problematic (Craig et al. 2003). As it was not possible to verify from the questionnaire whether the accident was clearly related to loss of balance, we included also accidents that may have been otherwise imposed which may have influenced the results.

According to literature, the majority of youth fractures occur in the upper extremity (Rennie et al. 2007). We chose to include also fractures of the lower extremity, with the reasoning that in trying to prevent a perturbation, a person may use different strategies to try to restore the upright balance (i.e. stepping strategy).

11 CONCLUSIONS

In this study, no associations of body sway parameters with fracture, body weight, or with the level of leisure time physical activity were found in these healthy adolescent girls. These results indicated that the assessments of body balance with current setting in healthy adolescent girls may not be sensitive enough to capture the expected differences between fracture and none-fracture groups, between physically active and inactive groups and between overweight and normal weight groups. However, lower limb force was weakly inversely associated with some of the body sway parameters indicating that strengthening the lower limb muscles would improve postural stability.

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